

**CYCLING PERFORMANCE FOLLOWING
INTERMITTENT HYPOXIC TRAINING
USING AN HYPOXICATOR**

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Dedication

I dedicate this work to my wife, Melissa, who has been a source of motivation and strength throughout this five-year mission. We have had to cope with so many events along the way including our marriage, illness, DIY projects, a new job and potential relocation and, in 2003, Melissa gave birth to our daughter, Sophie, the most exciting event in my life. In the midst of these challenges, we have had so much fun and I thank you for all your support and faith.

ABSTRACT

Live high - train low altitude camps can enhance endurance power at sea level by 1-2% (Levine & Stray-Gunderson, 1997). More convenient methods to simulate altitude exposure are now available, but their effects on performance are less well characterized. In this study, we investigated intermittent hypoxic training (IHT) using an Hypoxicator, a device that produces oxygen-depleted air that athletes breathe intermittently through masks in a small group at a central venue.

Twelve highly-competitive, male cyclists and multi-sport athletes (IHT group) underwent IHT in two, four-week bouts separated by eight weeks. Bout one consisted of 20 one-hour exposures and bout two 18 exposures where normal and low-oxygenated air was breathed in alternating five-minute intervals. The percentage of oxygen inhaled by the subjects was adjusted to produce an oxygen saturation of the blood of 88-92% in the first week of the study, decreasing to 76-80% (equivalent to an altitude of approximately 6000m) in the final week. A control group of 13 similar athletes did not use the Hypoxicator. Performance trials and blood tests were at four-week intervals; there were 3 trials (familiarization and reliability) before use of the Hypoxicator, 3 trials after to determine the effect of simulated altitude, then a second four-week exposure and one more trial. The measures of performance were mean power in a 16-km time trial on a Kingcycle ergometer (IHT group only) and power in a lactate-threshold test at 3 mmol/L above baseline (both groups). The measures from the blood tests were haemoglobin and haematocrit.

There was a gradual but erratic improvement in performance in the time trial and lactate threshold tests over the course of the study in both groups, indicating an improvement through training. Relative to the last baseline test (Trial 3), the IHT

group showed a 0.6% decrease in mean power over and above the effect of training in the 16-km time trial in Trial 4, nine days after last use of IHT. There was a 0.3% increase in mean power independent of the training effect in Trial 7, after the second round of altitude exposure. Uncertainty in these changes in performance was $\pm 3.5\%$ (95% confidence interval). The changes in lactate threshold in trials 4 and 7 indicate a possible improvement as a result of IHT exposure. Uncertainty in these changes was $\pm 4.0\%$. There were negligible changes in the haemoglobin and hematocrit of either group at any time. There was small evidence of high responders, who were probably subjects with the DD genotype for the angiotensin converting enzyme gene. The time exposed to IHT had no bearing on performance and there was no evidence “peak” in results at either four or eight weeks after exposure to IHT.

In summary, four weeks of IHT exposure probably resulted in a trivial effect on 16-km time-trial performance and the effort-independent measures provided no further clear-cut evidence of a performance improvement.

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CHAPTER ONE

Introduction

Stress to the body's physiological systems takes place when breathing air that is low in oxygen and prolonged exposure will induce advantageous adaptations. The question posed by athletes, coaches and scientists is whether such adaptations improve athletic endurance performance when competing at sea level.

Since the 1968 Mexico City Olympics, athletes have lived and trained at altitudes of around 2,500m in an attempt to gain a competitive edge. After almost four decades of research, the scientific literature has produced only "ambiguous and inconclusive results" about the benefits of altitude training (Berglund, 1992 p. 290). However, a few recent studies have addressed a modified approach to altitude exposure and have found the most positive results so far. It seems that living at moderate altitudes (1,500-3,000m) and training at or near sea-level on a daily basis will probably increase high-intensity endurance performance by 1-2% (Levine et al., 1991; Levine and Stray-Gunderson, 1997). The term "live high - train low" was coined to describe this practice.

There are a few downsides to a live high - train low altitude camp, including reduced protein synthesis (Adams et al., 1975; Wolfel et al., 1991; Narici and Kayser, 1995; Beidleman et al., 1997; Clanton and Klawitter, 2001), the

inconvenience of training conditions, increased risk of overtraining (Rusko, 1993), emotional stress (Liu et al., 1998) and the cost of travelling to the few places in the world where the geography and training facilities allow this practice.

Recently, manufacturers have attempted to replicate the live high - train low practice by providing athletes with devices designed to simulate the altitude experience. These devices include hypoxic gas inhalers, barometric chambers, altitude (hypoxic) tents, and nitrogen apartments. One such hypoxic gas inhaler is called the Hypoxicator and its use is characterised by a protocol called intermittent hypoxic training (IHT).

There is almost no research addressing the benefits of IHT for athletic endurance performance, although the device and protocol are well marketed (e.g. GO2altitude, 2003). Of the limited studies available, most have poor methodology e.g. lack a control group, have small subject numbers. Use of the Hypoxicator and IHT by high-profile, elite athletes – searching for tiny performance improvements – is becoming more common. Therefore, it is important that the sporting fraternity receives unbiased, independent advice regarding the effectiveness of this moderately-expensive practice. A controlled study was requested by a group of New Zealand national coaches in the lead-up to the 2000 Sydney Olympics.

It is possible IHT could work in one or both of two ways. Firstly, the hypoxia could trigger the typical central (erythropoietic and respiratory) and peripheral (metabolic and morphological) responses to altitude, which are assumed to be

largely responsible for improved endurance performance following a moderate-altitude camp. Secondly, IHT could mimic the response to a series of 5-minute aerobic training intervals. Promoters of the device have postulated both to take effect (Dr Alexei Korolev and Dr John Helleman, personal communication). This study focussed on how central adaptations impacted on performance.

A controlled, repeated-measures design was used to examine the extent to which high-intensity endurance performance changes after IHT use. To account for performance changes, we measured blood parameters (lactate, haemoglobin and haematocrit) that alter when training at altitude (Berglund, 1992) and genotype for the gene, angiotensin converting enzyme (ACE). The ACE genotype exists in three forms (I-I, I-D, D-D), with the I-I form being more prevalent in extreme mountaineers and possibly linked to superior aerobic and anaerobic response to physical training (Montgomery et al., 1998, Montgomery et al., 1999, Folland et al., 2000).

Quantifying the effect of IHT on performance could assist athletes with their choices about training methods and their preparation for competition. If performance improvements were comparable with the live high - train low method, substantial research would be expected in the future.

CHAPTER TWO

Review of the Literature

Introduction

Two terms, “adapted cell hypoxia” and “dysoxia”, describe the responses of tissues to restricted oxygen availability. Adapted cell hypoxia refers to the point where the unavailability of oxygen is non-saturating for cytochrome oxidase, but normal aerobic metabolism still takes place. Dysoxia refers to the point where the restriction of oxygen prevents substrate metabolism via the Krebs Cycle and the energy yield must come from anaerobic pathways (Clanton and Klawitter, 2001). Both responses are likely to occur when athletes live and/or train at moderate altitudes (1,500-3,000m). The question posed by athletes, coaches and scientists is whether such adaptations improve endurance performance at sea level.

This review of scientific literature will substantiate the logic behind developing devices and protocols to simulate a live high - train low environment. It will also investigate whether intermittent hypoxic training (IHT) could improve endurance performance by triggering the typical responses to altitude or a series of aerobic training intervals. Finally, it will use the current evidence to help determine the best use of IHT and appropriate measures of testing its effectiveness.

Can A Moderate-Altitude Training Camp Improve Performance?

Endurance athletes have been attending altitude-training camps for a long time – at least before the 1968 Mexico City Olympics – and many are convinced that sea-level performance improves as a result. Some New Zealand sports (e.g. NZ Triathlon) insist it is imperative in the build-up to their pinnacle events.

The altitude benefits of training above 3,000m do not appear to outweigh the potential altitude illnesses (Berlund, 1992). Since the 1960s, many researchers have addressed the performance effect following two-four weeks living and training at moderate altitudes (1,500-3,000m). However, debate exists between scientists as to the effectiveness of altitude-training camps. The debate continues due to two main reasons a) the inconsistency in findings and b) the lack of methodological rigour in many studies.

The Inconsistency of Findings

Many studies have found a positive effect of altitude training on performance. Daniels and Oldridge (1970) provided altitude training at 2,300m for six elite runners. On return to sea level, one runner broke the one-mile world record and five of the runners ran personal best times. Mittila and Rusko (1996) demonstrated a significant improvement in a cycling time trial performance following 11 days in an altitude house set to approx 3000m (14.2% O₂). Mizuno et al. (1990) examined well-trained cross-country skiers after just two weeks living at 2,100m and training at 2,700m and reported a 17% improvement in run time to exhaustion.

Conversely, the literature contains studies depicting negative performances following altitude training. In 1991, Levine and Stray-Gundersen examined 5-km time-trial running performance in trained runners living at either 2,500-3,000m or 1,200m for four weeks. Training was matched between groups and consisted of a combination of aerobic endurance and aerobic power development (a training method later proposed to be effective when training at altitude (Burtcher et al., 1996)). Time-trial performance deteriorated in both groups and there was no significant difference between groups. Similar deteriorations were reported in national representative rowers (Jensen et al., 1993) and Rusko (1996) described improvements in the study's control group over the athletes training at altitude.

Finally, Telford et al. (1996) took elite distance runners to 1760m for four weeks and found no change in 3.2km time trial performance relative to a control group that trained at 610m. Adams et al. (1975) were also unable to detect any change in 2-mile running performance after three weeks of hard training at 2,300m.

The maximum ability of an athlete to utilise available oxygen to produce energy via the Krebs Cycle is referred to as maximum oxygen uptake (VO_2max). Although several other factors (e.g. the economy of movement, lactate threshold and motivation) play a role in determining endurance performance outcome, VO_2max is often measured to indicate the effectiveness of the aerobic energy system.

VO₂max has been a focus of several studies attempting to determine the benefits of a moderate altitude training camp and the results have been varied. Significant improvements in VO₂max have been found by Faulkner et al. (1967) and Burtscher et al. (1996) while a small improvement was reported by Adams et al. (1975).

In contrast, VO₂max has not always been demonstrated to improve following altitude exposure. Ingjer and Myhre (1992), Mizuno et al. (1990) and Rodriguez et al. (1999) all failed to verify improvements in VO₂max. Mizuno et al. (1990) stated the lack of increase may be attributed to level of athletes studied, type of altitude intervention and training intensity at altitude.

Interestingly, the same inconsistencies are evident in studies examining anaerobic performance following moderate altitude exposure. Martino et al. (1995) and Nummela et al. (1996) report improvements in performance while Rusko et al. (1996) report a performance decrement.

Research Design

Many studies addressing altitude training for athletes have been poorly designed. Inadequate methodology may explain the inconsistency of findings and certainly justifies some scientists' scepticism surrounding moderate-altitude training camps.

Telford et al. (1996) noted the importance of incorporating a control group after finding no improvement in 3.2km time-trial running performance. Unfortunately, some studies have incorporated neither a control group nor other measures to regulate against external influences. For example, the study by Faulkner et al. (1967) did not contain a control group and the authors failed to quantify training load before and during the experiment. They concluded that some subjects demonstrated a training effect during the course of the study. Mizuno et al. (1990) also failed to incorporate a control group. In addition, Bonning (1997) identified many experiments that contained small subject numbers, which reduced the statistical power of the study.

Like the Faulkner et al. (1967) experiment, some studies do not accurately report the training volume (duration and intensity) of subjects throughout the course of the investigation (e.g. Terrados et al., 1988; Ingjer and Myhre, 1992; Rodriguez et al., 1999). Where necessary, studies should also control for the “training-camp effect”. This effect describes a likely improvement in performance as a result of the additional motivation, well-being and rest gained by a group almost solely training without the normal day-to-day distractions such as employment. A feature of a study by Levine and Stray-Gundersen (1997) was the fact that both the altitude and control groups trained in a camp environment.

There is strong likelihood of a placebo effect during a moderate-altitude training camp and the placebo effect can account for around 3.8% improvement in performance (Clark et al., 2000). Generally, groups are unable to be blinded to the altitude condition because of the geographical environment (of note, however, is that blinding of the altitude dose was achieved in a simulated-altitude study (Clark et al., 1999)). It is therefore necessary to control for all motivating factors (e.g. recording of training volume, control for the “training-camp effect”) and incorporate measures unalterable by subjects such as blood parameters.

It is imperative that exercise tests are specific to the subject's mode of training. Both Burtcher et al. (1996) and Faulkner et al. (1967) demonstrated increases in both VO_2max and maximum workload following a bout of altitude training. However, both studies tested subjects on a cycling ergometer even though the athletes were runners (Burtcher et al., 1996) or a mix of runners and swimmers (Faulkner et al., 1967).

The Downside of Altitude-Training Camps

Aside from the mixed results in the literature, there are reasons why training at moderate altitude might not be advantageous. The most likely is the necessary reduced training intensity at moderate altitude (Rusko, 1996). Mairbaurl (1994) described how a decrease in atmospheric PO_2 resulted in a decreased amount of oxygen in the blood. During moderate and intensive aerobic exercise at moderate or high altitude, a reduced oxygen supply to the working muscle (Wolfel et al., 1991) can cause a shift toward anaerobic metabolism illustrated in part by increased heart rates (Wolfel et al., 1991) and blood lactates (Rusko,

1996). These physiological changes limit the training effect of the intended aerobic conditioning.

In addition, the increased contribution of anaerobic glycolysis to energy production will decrease blood pH and, combined with the typical increase in temperature when exercising, serves to shift the oxygen dissociation curve to the right (Mairbaur, 1994). A right shift in the oxygen dissociation curve results in a lower saturation of oxygen in the blood and, while beneficial in the periphery (by assisting the release of oxygen to the working muscle), will also inhibit the ability to uptake optimal amounts of oxygen in the lungs.

Reductions in body mass, lean muscle mass and protein synthesis have been experienced in acute (Narici and Kayser, 1995) and chronic (Adams et al., 1975; Wolfel et al., 1991; Beidleman et al., 1997; Clanton and Klawitter, 2001) hypoxic conditions. Training can help offset muscle wasting but hypertrophic responses are still significantly lower than experienced at sea level (Narici and Kayser, 1995). It should be noted, however, that reductions in body mass are not always observed (e.g. Mizuno et al., 1990).

Plasma volume has been reported to drop after exposure to moderate and high altitude (Berglund, 1992; Rusko, 1996; Bonning et al., 1997). The drop in plasma volume can cause a reduction in cardiac output (Wolfel et al., 1991), stroke volume (Rusko, 1996) and VO_2max (Williams et al., 1986) despite some improved cardiac function (Liu et al., 1998). The outcome is a rise in heart rate and reduced training quality.

Rising haematocrit (volume of red blood cells as a percentage of total blood) with reduced plasma volume results in increased blood viscosity, which results in energy inefficiency via increased vascular resistance (Wolfel et al., 1991) and poor microcirculation. Haematocrit values over 50% are banned by the International Cycling Union and have been linked to the death of athletes involved in the practice of “blood doping” (American College of Sports Medicine Position Stand, 1996).

Overtraining can also be a factor to contend with during an altitude training camp, characterised by raised resting cortisol levels (Rusko, 1993). The additional stress of training under hypoxic conditions may inhibit physiological adaptation. Such an example is a reduction in erythropoiesis in the bone marrow (Bonning, 1992).

Some athletes may respond better than others to a hypoxic stimulus. Chapman et al. (1998) determined that elite athletes who have ventilatory flow limitations cannot increase maximal exercise ventilation in mild hypoxic conditions (18.7% oxygen) compared to athletes with normal ventilatory flow. Ingier and Myhre (1992) reported that athletes with lower blood parameters (haematocrit and haemoglobin) are more likely to increase these values through a bout of altitude exposure. In a recent literature review, Rusko (1996) writes “All these data attest that altitude training may increase sea-level VO_2max in some athletes but individual responses are so different ...” (p. S48).

Using the scientific evidence presented, it is possible that the positive effects of altitude exposure may not offset reduced or negative physiological effects, most often amounting to a reduced training intensity. In fact, Engfred et al. (1994) found that subjects living and training at sea level had improved cycling time to exhaustion compared to those training at moderate altitude. There is also the inconvenience of training conditions, emotional stress (Liu et al., 1998) and financial limitations that can make altitude training camps less appealing.

The Benefits of the Live High - Train Low Protocol

In 1991, Levine et al. looked at a small number of runners (n=6) who lived at 2,500m and trained at 1,300m compared to controls (n=3) who lived and trained at 1,300m. Training was matched for both groups and after four weeks the experimental group showed a significant 2.5% improvement in 5-km time-trial running performance. Subjects also showed corresponding improvements in blood volume and VO_2max . The authors gave birth to the term “living high - training low”, meaning performance gains can be maximised with the benefits of living at moderate altitude whilst retaining the training quality nearer to sea level, in this case 1,300m.

In a subsequent, small (n=6), uncontrolled study, Stray-Gundersen and Levine (1994) examined the time-course of performance improvement using the same methodological design. The conclusion was that 5-km time-trial performance was enhanced immediately following the live high - train low method but was lost within two weeks. However, the authors compared the post-altitude measures to those four weeks pre-altitude rather than those immediately pre-

altitude. Subjects spent the first four weeks of the study at sea level and showed very good training improvements. These improvements should not have been grouped with the four weeks at the altitude.

In 1997, Levine and Stray-Gundersen produced a landmark paper, noted for its strong methodological design and positive results. Thirty-nine competitive runners, whose 5000m time averaged almost 80% of the world record, were randomised to one of three groups; live low – train low, live high – train high or live high – train low. All subjects followed similar training for four-weeks at sea-level prior to the altitude intervention. Upon return from altitude exposure, the live high – train low group improved their 5000m time by approximately 1.5% while the live low – train low group performed worse by approximately 2.5%. This gap widened further to 4.5% after one week after altitude exposure. The results of the live high – train high group remained fairly stagnant, although they showed a tendency to improve by about 0.5% three weeks after altitude exposure. The improvement in performance of the live high – train low group was accompanied by increases in blood volume, red blood cell mass and haemoglobin compared to the live low – train low group.

Haematological parameters important to endurance performance have not always improved. Ashenden et al (1999a; 1999b) reported no change in reticulocyte production (red blood cells that are just a few days old) and haemoglobin mass (oxygen carrier in the red blood cell) in elite athletes after 12 and 23 days following a live high – train low protocol, albeit with simulated altitude.

Devices Available to Simulate the Live High - Train Low Condition

There are now many devices that simulate the low-oxygen atmosphere of mild (<1,500m), moderate (1,500-3,000m) and high (>3,000m) altitude exposure. These devices generally propose the use, or modified use, of the live high - train low protocol. The benefits and downsides of each device are presented in Table 1. While the effect on performance is not certain with any of the devices, they can simulate the live high - train low condition at less financial cost and allow the athlete access to their normal training facilities whilst remaining with their support network.

The Use of Intermittent Hypoxic Training

Of the above devices, intermittent hypoxic training to improve endurance performance is generally only promoted with the hypoxic gas inhaler. IHT refers to daily or twice-daily exposure (of approximately one hour per session) to low-oxygenated air (9-20% oxygen) interspersed by sea-level air (21% oxygen) whilst subjects are at rest. The intervals are about five minutes of low-oxygenated air followed by around five minutes of “normal” air.

IHT has been used in Russia for many years, mainly in cardiovascular medicine, respiratory medicine, gastrointestinal medicine, gynaecology and degenerative diseases (Hellemans, 1999; GO2Altitude[®], 2003). Only since 1998 has IHT been introduced to endurance coaches and athletes in New Zealand as a mechanism to improve aerobic performance (Dr Alexei Korolev, personal communication).

The use of IHT is so new to athletes that no studies have addressed the most effective acute and chronic frequency of exposure, acute and chronic duration of exposure, time inhaling the low-oxygenated air or the most effective percent of oxygen in the gas mixture. In addition, like many other devices (Rusko, 1996), no aspects of long-term safety have been studied in Western literature.

Table 1: *The benefits and downsides to various commercial devices used by athletes to simulate the lowered oxygen availability at altitudes above sea level.*

Simulated-Altitude Device	Benefit	Downside
Nitrogen Apartment	<ul style="list-style-type: none"> • Research addressing effect on performance. • Allows prolonged exposure. • Little alteration to normal daily routine. • Living comfort. 	<ul style="list-style-type: none"> • Financial cost. • Availability (only one possibility in New Zealand). • Tends to be an inability to simulate high altitudes. • Non-portable.
Barometric Chamber	<ul style="list-style-type: none"> • Research addressing effect on performance. • Can simulate high altitudes. • Availability. 	<ul style="list-style-type: none"> • Living comfort. • Tends to prevent prolonged exposure (due to living comfort). • Financial cost. • Non-portable.
Altitude Tent	<ul style="list-style-type: none"> • Financial cost. • Portable. • Availability. 	<ul style="list-style-type: none"> • Living comfort (motor noise can prevent sleep). • Tends to prevent long-term exposure. • Tends to be an inability to simulate high altitudes. • Effect on performance not studied.
Hypoxic Gas Inhaler	<ul style="list-style-type: none"> • Financial cost. • Can simulate high altitudes. • Living comfort (due to short exposures). 	<ul style="list-style-type: none"> • Effect on performance not studied. • Long-term exposure prevented. • Not portable.

Some studies have addressed the benefits of exercising during intermittent hypoxic exposure (using a hypobaric chamber) but with contrasting results. In a one-off exposure to a simulated altitude of 4,300m, Beidleman et al. (1997) found increases in blood glucose, glycerol and free fatty acid levels (but not cortisol) in subjects exercising compared to those resting. In contrast, Rodriguez et al. (1999) found no differences in haematology measures between exercising and non-exercising subjects during intermittent hypobaric exposure.

Effect of IHT on Performance

Much of the IHT literature is not reported in English (usually reported in Russian) and translations are difficult to attain. Only studies published (or translated) in English have been presented in this literature review.

Latyshkevich et al. (1993) found increased work output following 24 days of IHT in competitive volleyball players, although the authors did not detail the post-exercise testing period. The increased work output was accompanied by decreases in VO_2 , heart rate and ventilation during exercise to exhaustion.

Clark et al. (1999) conducted a small, yet methodologically-strong study examining IHT. Eight rowers followed a hypoxic protocol consisting of five minutes of low-oxygenated air (12.2%) and five minutes of normal air. Rowers followed the IHT protocol for 14 days (90 minutes per session). Performance was examined using a rowing ergometer test designed to simulate a race situation. Features of this study were the use of a control group and the blinding of all subjects to the percentage of oxygen inhaled. While the sample

numbers in the study were very small, no change in performance, $\text{VO}_{2\text{max}}$, lactate threshold or haematological parameters (red blood cell mass, haemoglobin, haematocrit, and percent reticulocytes) were detected. However, the authors did not overlook the possibility that performance improvements may have been apparent subsequent to testing the subjects.

Hellemans (1999) presented some pilot work, where ten competitive and elite athletes showed a 2.9% improvement in time-trial performance. The athletes used IHT in five-minute intervals for one hour, twice daily, for a total of 18 days. Subjects alternated between breathing normal air and 10% oxygen for the first ten days and normal air and 9% oxygen for the remainder of the study. The performance improvement was accompanied by increases in selected blood parameters. Haemoglobin, haematocrit and reticulocytes increased by 4.3%, 5% and 30.3% respectively. While the study was uncontrolled, lacked statistical analysis and power and did not report pre-IHT training improvements, it provided the further evidence for a potential performance improvement using IHT. Furthermore, the author made comparisons to the expected haematological changes with altitude training and drew links between the performance and haematological improvements.

In the same year, Rodriguez et al. (1999) published a study demonstrating a 3.9% increase in maximal exercise time in a modified Bruce Protocol endurance test after just 9 days of intermittent hypobaric exposure (3-5hours/session) at 4,000-5,500m. While the hypoxic protocol differed substantially to that of Clarke et al. (1999) and Hellemans (1999), it contributed to the evidence that short bursts of reduced oxygen inhalation than that of a typical altitude training camp

may improve aerobic power performance. In addition, the ability to perform IHT in a resting state could mean that IHT could be performed by athletes over and above their normal physical training load. What was also exciting about this study was that the performance improvement was accompanied by a significant right shift in lactate-velocity curves. However, VO_2max was not significantly altered during the study.

While the improvements found by Rodriguez et al. (1999) are impressive, the ability to relate the results to elite athletes is questionable. The subjects in this study were high-altitude climbers whose requirement for aerobic endurance is greater than for aerobic power (as indicated by the average subject relative VO_2max score of around 51 ml/kg/min). In addition, time-to-exhaustion tests, such as the Bruce Protocol, are very reliable but time needs to be converted to power to best correlate to performance (Paton & Hopkins, 2001).

Can IHT Replicate the Physiological Adaptations Found In Altitude and Simulated Altitude Studies?

It is possible IHT could work in one or both of two manners. Firstly, the exposure to hypoxia could trigger the typical central (erythropoietic and respiratory) and peripheral (metabolic and morphological) responses to altitude, which are assumed to be largely responsible for improved endurance performance following a moderate altitude camp. Secondly, IHT could mimic the typical responses to a series of 5-minute aerobic training intervals. Both have been postulated to take effect by promoters of the device (Dr Alexei

Korolev and Dr John Hellemans, personal communication). The following two sections examine the evidence for these suggestions.

Haematology

There is little evidence to date that suggests IHT improves endurance performance to levels observed using a live high - train low protocol and certainly not to the levels expressed by some promoters of the Hypoxicator (The Oxygen Centre, Auckland, New Zealand, personal communication). However, it may be possible that IHT elicits physiological responses similar to those observed during a moderate altitude training camp. Evidence for this hypothesis comes from the study by Rodriguez et al. (1999), where the 4% improvement in time to exhaustion during a modified Bruce protocol was also accompanied by an 11.1% increase in haematocrit concentration and a 17.7% increase in haemoglobin concentrations. The magnitude of these changes was consistent with an earlier study using a similar protocol over 18 days (Casas et al., 1997 cited in Rodriguez et al., 1999).

Oxygen is primarily carried through the blood to the working muscles via haemoglobin – approximately 1.34ml oxygen can be bound per gram of haemoglobin (Mairbaur, 1994). Increases in haemoglobin concentration result in a proportional increase in the amount of oxygen transported and delivered to the working muscle (Mairbaur, 1994) up to a concentration of about 210g/L (Ekblom, 1996) and has been related to improvements in VO_2max (Gore et al., 1997). Ekblom (1996) notes “...hemoglobin concentration is an important

parameter for determining maximal aerobic power and physical performance” (p. S41).

Typical values of haemoglobin for aerobically-trained men are 140-170g/L and for women are 120-150g/L. Total haemoglobin is about 50% higher in endurance athletes compared to non-athletes but the concentration remains about the same as non-athletes because of a higher plasma volume in athletes (Berglund, 1992). Researchers should therefore consider alternations in plasma volume when determining “actual” changes in haemoglobin concentration (Friedmann et al., 1999). Increases in haemoglobin of around 3-14% during a short stay (e.g. 18-21 days) at moderate altitude are well characterised (Faulkner et al., 1967; Berglund, 1992; Friedmann et al., 1999) but not at mild altitude (Gore et al., 1997).

Increased red blood cell mass, observed as increased haematocrit values, will allow increased haemoglobin in the cell (Rusko, 1996) and therefore greater oxygen-carrying capacity. Although we know that red blood cell mass can be increased in non-athletes, even without altitude exposure (Wolfel et al., 1991), many studies have shown red cell mass to increase as a result of moderate altitude (Faulkner et al., 1967; Berglund, 1992; Ingjer and Myhre, 1992; Rusko, 1996; Rodriguez et al., 1999). Stray-Gundersen et al. (1993) found a 9% increase after four weeks of training at 2,500m. Rusko (1996) analysed years of red cell mass data collected on Finnish National distance runners and racewalkers after altitude training and concluded an overall, statistically significant, 6% increase.

Wolfel et al. (1991) measured a significant increase in haematocrit (41.2 – 43.5%) within the first four hours of landing at 4,300m. Athletes with lower haematocrit (e.g. 43%) and haemoglobin (e.g. 14g/100ml) levels are more likely to increase their values through altitude camp exposure, responding with improved blood lactate status during submaximal steady-state exercise (Ingjer and Myhre, 1992). Reinfusion of red blood cells back into the body, as in the practice of blood doping, provides clear evidence of the benefit of red blood cells in improving endurance performance (American College of Sports Medicine Position Stand, 1996).

The hormone, erythropoietin (EPO), is a glycoprotein produced mainly in the kidney (also in the liver) and stimulates erythropoiesis, the formation of red blood cells in the bone marrow (Mairbaur, 1994). The concentration of EPO varies with time of day, physical activity and mental stress (Ekblom, 1996) but sustained formation and release of serum EPO can be a result of altered venous PO_2 , arterial oxygen saturation, red blood cell mass and haemoglobin concentration (Mairbaur, 1994). There is no doubt that external administration of EPO can enhance aerobic performance (Ekblom, 1996) so EPO would appear to be an advantageous benefit derived from hypoxic exposure.

Acute exposure to hypoxia results in release of mainly newly-formed EPO into the blood. Production and release of EPO during prolonged exposure normally declines (Savourey et al., 1996; Boning et al., 1997), although erythropoiesis remains stimulated (Mairbaur, 1994). While both a single exposure to hypoxia or strenuous exercise can trigger EPO production and erythropoiesis (partly via decreases in arterial oxygen saturation) exercise at altitude may stimulate

erythropoiesis over and above altitude exposure alone (Mairbaurl, 1994). There appears to be an additive effect.

Knaupp et al. (1992) examined the time-course of changes to serum-EPO concentration in subjects inhaling 10.5% oxygen in a series of continuous and intermittent bouts. Non-significant rises between zero and twenty-five percent were shown in the five hours following one-off, five- and sixty-minute bouts. However, a significant rise (52% above baseline) was observed 2 hours post-inhalation in subjects following an intermittent protocol (2.5 minutes of low-oxygen air followed by 1.5 minutes of room air for a bout lasting 240 minutes).

Rises in serum-EPO concentration similar to that observed in the intermittent protocol have been observed after 120 minutes of continuous exposure (Eckardt et al., 1989; Knaupp et al., 1992; Klausen et al., 1996). During the intermittent protocol, approximately 110 minutes of the time was spent below 90% arterial oxygen saturation. Klausen et al. (1996) reported that rises in EPO are related to the lowered PO_2 in the arterial blood (and not the increased arterial pH and haemoglobin oxygen affinity) so it is possible that the increase in EPO observed following the intermittent protocol is related to the absolute time of lowered oxygen saturation (and probably lowered oxygen partial pressure. To date, no studies have examined whether intermittent inhalation protocols produce superior rises in serum-EPO concentration compared to a continuous protocol of the same duration.

Altitude exposure may speed the release of new red cells from bone marrow into the blood (Mairbaur, 1994; Bonning et al., 1997). The younger erythrocytes, called reticulocytes, can be released quicker (five days instead of seven days) under high serum erythropoietin concentrations (Berlund, 1992) and their high deformability can improve microcirculation (Mairbaur, 1994). This deformability might lead to more energy-efficient delivery of oxygen to the working muscles.

The younger red blood cells contain higher concentrations of 2,3-diphosphoglycerate (2,3-DPG) compared to the older cells. 2,3-DPG is a substance located within the red blood cell that assists in the release of oxygen and results in a right shift in the oxygen dissociation curve (Bonning et al., 1997; Mairbaur, 1994). Oxygen dissociation is a term given to the unloading of oxygen from haemoglobin (and into the muscle cell) and can be plotted against the pressure of oxygen (PO_2) in the blood. Rises in CO_2 , adenosine triphosphate (ATP) and temperature and a decrease in pH are also factors that enhance the release of oxygen from haemoglobin (Mairbaur, 1994) and shift the oxygen dissociation curve to the right.

In hypoxic conditions, atmospheric PO_2 is reduced and, consequently, the percentage of red blood cells in the arterial blood saturated with oxygen (S_aO_2) is correspondingly reduced. This relationship can be illustrated in the oxygen dissociation curve (Mairbaur, 1994). Although ventilation rises (Lawler et al., 1988; Savourey et al., 1996) in an attempt to off-set the lowered S_aO_2 , the decreased S_aO_2 stimulates erythropoiesis.

There is sparse evidence for adaptations to S_aO_2 following a chronic dose of hypoxia. At sea level, S_aO_2 was not shown to change either immediately after or 1-2 months after acclimation in a hypobaric chamber consisting of eight hours per day for five days set at 4,500-7,500m (Savourey et al., 1996). However, after the acclimation period, subjects were briefly exposed to a simulated altitude of 4,500m and S_aO_2 was similar to the level shown at sea level. This indicates some physiological adaptation had taken place but there is no evidence to suggest it improved endurance performance.

There is certainly overwhelming evidence that haematological adaptations take place during chronic exposure to moderate and high altitude. In addition, some evidence has also been presented that support the notion of haematological changes following IHT. However, despite the above findings, Engfred et al. (1994) found that short bursts of training for untrained individuals at a simulated altitude of 2,500m resulted in no change in EPO, 2,3-DPG, haemoglobin, haematocrit or hormonal indices and concluded "...exposure to hypoxia for approximately 1 h per day for 5 weeks does not result in acclimatization" (p. 307).

Muscle and Metabolism

Few studies have examined the effect of altitude exposure on muscle morphology or metabolic enzyme activity. However, initial research indicates advantageous effects following exposure to hypoxia. Terrados et al. (1988) had highly-trained cyclists perform all training in a barometric chamber (set to simulate 2,500m) for 3-4 weeks. Relative to their controls, no significant change to muscle fibres, capillary distribution or aerobic enzymes was

apparent. However, in a subsequent study by the same authors (Terrados et al., 1990), improved methodology resulted in a significantly greater time to exhaustion, increased concentrations of myoglobin and citrate synthase activity (markers of oxidative capacity) when training in hypobaric conditions (set to simulate 2,300m) compared to normobaric conditions. Fibre type and size as well as the activity of anaerobic enzymes did not change under hypoxic conditions. These findings are comparable to Melissa et al. (1997), who also detected an increase in citrate synthase activity after an eight-week, hypoxic, training study.

Mizuno et al. (1990) discovered increases in muscle capillarisation, enzyme activity (e.g. citrate synthase) and aspects of muscle cell structure after just two weeks of training above 2,500m. However, they concluded that the adaptive changes were a result of training volume and not hypoxic stimulus. Interestingly, they attributed the improved run time to exhaustion to increased buffering capacity of the muscle. Finally, Clanton and Klawitter (2001) noted variable results in myoglobin concentration and Krebs Cycle enzyme activity when examining a large number of studies on humans and animals experiencing both intermittent and chronic hypoxic conditions.

Lactate measures, which can be very reliable (Pfitzinger & Freedson, 1998) and correlate highly with endurance performance (Kenefick et al., 2002; Bird et al., 2003), tend to be lowered after hypoxic exposure and exercise. Bender et al. (1989) reported a lower concentration of blood lactate after exposure to 4,300m, although the subjects in this study were not well trained. Using elite athletes, Ingjer and Myhre (1992) found lower blood lactate values during a submaximal

exercise after completion of altitude training. At the end of an incremental cycle test (to exhaustion), competitive athletes returning from an altitude camp were shown to have significantly lower peak blood lactate levels compared to controls training at sea level (Burtscher et al., 1996). Analysis of the lactate v workload plot indicates a clear downward trend throughout the test three- and sixteen-days following altitude exposure. Some of the mechanisms proposed by Clanton and Klawitter (2001) for the lowered lactate levels post-altitude include a) decreased glycolytic flux, b) decreased glycogen storage, c) changes in buffering capacity (also observed by Mizuno et al., 1990) and d) changes in efficiency of muscle contraction.

There is also a possible decrease in glycolytic enzymes (phosphofructokinase and lactate dehydrogenase) and glucose / glycogen utilisation following hypoxic exposure but this trend is not clear (Terrados, 1992; Clanton and Klawitter, 2001). These studies, and those above, point toward possible improved aerobic energy production and a lesser reliance on anaerobic glycolysis. This being the case, theoretically, endurance performance following hypoxic exposure should be enhanced.

In summary, many studies examining the haematological, muscular and metabolic effects following real or simulated exposure to moderate or high altitude indicate an adaptive physiological response, although the magnitude and duration of the adaptation appears to vary throughout the literature. In some of these studies, the physiological response can be linked to improved performance. There is also some direct evidence that exposure similar to IHT could replicate some of the physiological responses of a moderate altitude

camp (Eckardt et al., 1989; Wolfel et al., 1991; Knaupp et al., 1992; Mairbaur, 1994; Klausen et al., 1996; Rodriguez et al., 1999). However, this evidence is not undisputed (Engfred et al., 1994).

Can IHT Replicate the Physiological Effects Found In

Aerobic Interval Training Studies?

Clanton and Klawitter (2001) proposed that intermittent exposure to hypoxic conditions (e.g. during obstructive sleep apnea, acute ventilatory failure, myocardial infarction and resuscitation) may cause different neural and physiological responses between each of the conditions and almost certainly compared to continuous exposure. However, the possible oxygen deprivation – regeneration pattern experienced in skeletal muscle during IHT might be closely related to that of high intensity aerobic training intervals of the same duration. Supporting this hypothesis is the suggestion of a reduction of PO_2 at the muscle through regular findings of lowered S_aO_2 (Williams et al., 1986) and muscle venous PO_2 (Schibye et al., 1998) when exposed to both training and hypoxic conditions. Clanton and Klawitter (2001) report a decreased PO_2 in a few *in vivo*, animal studies. Interestingly, highly aerobically trained athletes exhibit decreases greater than untrained individuals in S_aO_2 and arterial oxygen tension (Williams et al., 1986, Lawler et al., 1988).

In addition, many blood parameters are stimulated by both exercise and hypoxia. EPO release, red blood cell production and reduced mean cell age are examples, although the rises observed in the blood follow different time courses (Mairbaur, 1994). Red blood cell mass can be enhanced by training at

sea level (Wolfel et al., 1991) and altitude (Stray-Gundersen et al., 1993; Rusko, 1996), particularly in elite athletes (Rusko, 1996).

Aerobic interval training is a common training method as it can improve performance over and above the more-traditional continuous aerobic training (Lindsay et al., 1996). There is some evidence to suggest IHT improves performance by replicating the effects of high intensity, aerobic interval training. A single, high intensity, aerobic exercise bout results in similar effects to the oxygen dissociation curve (increases in CO₂ and 2,3-DPG production) compared to a bout of high altitude (Mairbaur, 1994). Aerobic interval training also increases red blood cell production, although this is as a result of mechanical destruction (Schmidt et al., 1988).

In summary, there is some, but not very much, evidence that the hypoxic effect and intermittent nature of IHT replicates the bouts of low muscular PO₂ experienced during high intensity, aerobic interval training. It is also possible that IHT stimulates similar physiological effects as interval training. Currently, there is no evidence that both effects are linked.

The Use of IHT

As previously mentioned, no Western research on athletes has attempted to study the variables associated with IHT (e.g. frequency of exposure, duration of exposure, interval durations and percent of oxygen in the gas mixture). Current use of the Hypoxicator arises largely from Eastern-block literature, which has generally focussed on medical interventions.

There are a few studies that could help determine use of IHT. Mairbaurl (1994) notes that erythropoietic activity rises linearly up to an altitude of approximately 4,000m, rises more steeply to 6,000m and then diminishes dramatically when the arterial saturation of oxygen drops below 60%. This could suggest simulating altitudes of around 6,000m might lead more quickly to the haematological responses described in the above sections.

Prolonged exposure to such high altitudes does pose a health risk to humans via the dysoxic response described in the introduction of this literature review. Clanton and Klawitter (2001) suggest it is possible that prolonged dysoxia can lead to impaired cellular function and even death. By alternating the inhalation of hypoxic and normoxic air, such health risks may be alleviated.

Mairbaurl (1994) stated "... the adjustment of the O₂-transport capacity by erythropoiesis is a slow response suitable for long term adaptation to hypoxia..." (p. 61). Liu et al. (1998) found limited or no change in the cardiac dimensions and cardiac function of well-trained athletes after two weeks living high and training low. These reports would suggest the typical three- to four-week period of altitude exposure generally employed by coaches and athletes is required to elicit improvements in performance.

However, Rodriguez et al. (1999) exposed subjects to much higher simulated altitudes than athletes would normally live in (4,000-5,500m for three-five hours per day) and found significant increases in red blood cell count, packed cell volume, reticulocytes and haemoglobin after just nine days of exposure. They also reported significantly lowered blood lactate values. Vallier et al. (1996) had

triathletes replace nine sea-level training sessions (over three weeks) with exercise in a barometric chamber set to replicate 4,000m. They found no change in lactate threshold or most haematological and respiratory parameters.

There is conjecture as to when performance might “peak” following return to sea level after a bout of altitude training. Significant improvements in a cycling time-trial test were found 5 days after living in an altitude house (Mattila and Rusko, 1996). In a study by Faulkner et al. (1967), maximum workload was enhanced at both three and twenty-one days following a period of altitude training. However, running time trial performance was not enhanced one day following altitude exposure but only twenty-one days afterwards. Total work capacity increased both three and sixteen days after a twelve-day altitude camp, but these were not significantly greater than the performances of the control group (Burtscher et al., 1996). However, blood lactate values were significantly lower in those training at altitude sixteen days after returning.

Ingjer and Myhre (1992) found the haemoglobin and haematocrit of seven elite athletes were significantly elevated one day, but not fourteen days, upon return from a 3-week altitude training camp at 1,900m as compared to pre-altitude levels. Savourey et al. (1996) reported elevated blood parameters (erythrocytes, packed cell volume, haemoglobin and EPO) one month following a combined bout of simulated- and high-altitude exposure. Bonning et al. (1997) measured blood volume and haemoglobin mass after extended exposure to moderate and high altitude and found it to be elevated two weeks following return to sea level. All parameters are likely to return to pre-exposure levels by two months (Savourey et al., 1996).

While the life-span of a red blood cell is approximately 120 days (Bonning et al., 1997), elite athletes show a decreased life-span (more like 90 days) mainly due to mechanical breakdown (Mairbaur, 1994) e.g. when the foot strikes the ground during running. However, the heightened concentration of red cells and the beneficial effects of younger cells to the oxygen dissociation curve (Bonning et al., 1997) could combine to display improved performance for up to four weeks following a stay at moderate altitude.

In summary, intermittent inhalation of air simulating altitudes of around 6,000m may best be used for three-five hours per day over a three or four-week duration (which should include at least nine sessions of exposure). After exposure to IHT, physiological and performance indices may “peak” anywhere from three days to four weeks.

Nutrient Intake

Inadequate nutrient intake can have a detrimental effect on erythropoiesis. Animal studies have shown that glucose and protein intake is important for normal EPO production (Berglund, 1992). In fact, a single day of protein deprivation has been shown to impair EPO production under hypoxic conditions (Anagnostou et al., 1977 cited in Berglund, 1992).

However, several studies have shown the most important consideration should be given to the availability of iron. Ferritin is a central element in the formation of haemoglobin and the oxygen-carrying capacity of the blood is almost entirely determined by the amount of haemoglobin. Therefore, it stands to reason that

iron would be a requirement to facilitate an increase in total haemoglobin during and after an hypoxic dose.

Stray-Gundersen et al. (1992) highlighted the importance of adequate iron stores prior to altitude exposure in iron-deficient runners. The runners trained for four weeks at 2,500m and showed no increase in red cell volume while those who had normal serum ferritin levels (men >30, women >20) showed an increase. The requirement of iron may be even greater during exposure to higher altitudes (Raynafarje et al., 1959). Berglund (1992) recommended oral iron supplementation (ferrous sulphate) of at least 200-300 mg/day in combination with 0.5-1g vitamin C/day (to increase gastrointestinal iron uptake) for subjects experiencing high altitudes.

In contrast, Friedmann et al. (1999) found that the availability of iron to non-iron-deficient boxers was not the limiting factor in either red blood cell production (including total body haemoglobin) or changes to VO_2max or maximal steady state running after 18 days of training at 1800m. These observations were confirmed by Ekblom (1996). No correlation was found between initial ferritin values and the change in red blood cell mass following a period of moderate altitude exposure (Rusko, 1996).

Using this limited research, it appears that athletes who are anaemic prior to a bout of hypoxia will most likely improve their haematological status by oral supplementation with iron. Non-anaemic athletes may not though with few adverse reactions to oral iron supplementation, little harm can come from this safeguard practice.

The Reliability of Exercise Testing

When choosing tests to measure performance, a key consideration is the reliability of the test being employed. Hopkins et al. (2001) conducted a meta-analytic review and found tests of constant power, power at lactate threshold, incremental to peak power and constant work tests will allow the least day-to-day variation.

Exercise Mode

Hopkins et al. (2001) noted that, owing to a lack of research, exercise mode cannot be regarded as a factor when determining exercise reliability. However, they did comment that the Concept II rowing ergometer probably produces the highest reliability and that, "Cycle ergometers that allow athletes to use their own racing bikes ... have produced some of the smallest CV [coefficient of variation¹]" (p. 229). In addition, it is imperative that athletes are tested using the same mode of exercise in which they train and compete.

¹ Coefficient of variation (CV) relates to the typical test error expressed as a percentage. It is derived by dividing the mean by the standard deviation of a sample (Hopkins, 2000). The smaller the CV, the more reliable the measure. CV allows easy comparison between groups with different means, particularly as it is expressed by a percentage.

Ergometer Reliability

The choice of ergometer should consider both systematic and random error.

These two types of errors will be considered separately in the following paragraphs. When an ergometer produces consistently higher (or lower) outputs than those known to be the true value, the difference is called systematic error. Provided the true reading can be obtained using a dynamic calibration device, subtracting or adding the magnitude of the systematic error can correct the ergometer reading. With the ability to control for such differences, systematic error is therefore of less concern than random error (discussed below).

Of the different cycling ergometers, friction-braked and electromagnetically-braked devices have been shown to have systematic errors often over 4% (Paton and Hopkins, 2001). Air-braked ergometers are generally very good and SRM cranks (a portable ergometer attached directly to the cycle rig in place of the normal pedal crank), in most instances, appear the best with a systematic error of approximately 2.5% and little error between different crank sets.

The Kingcycle ergometer is both an air-braked and friction-braked device.

Cyclists can connect their own racing bikes to the Kingcycle rig and are free to use their desired gearing or pedalling frequency throughout the test. The rear wheel of the bike drives a roller to simulate road resistance. The roller connects to a fan system to simulate air resistance. No calibration mechanism has been reported for the Kingcycle so the systematic error is unknown. However, in comparison studies between the Kingcycle and SRM cranks, SRM power output

was shown consistently to read 5-10% lower than that of the Kingcycle power (Balmer et al, 2000; Paton, unpublished report).

Random error refers to the typical day-to-day variation of an ergometer.

According to Paton and Hopkins (2001), no studies have been published that isolate random error in cycling ergometers. However, a considerable number of studies have examined the typical error of measurement concerning the athlete (also known as biological error) and the ergometer (Hopkins et al., 2001).

Knowing this type of error is probably more useful to practitioners because it is needed to determine whether a change in athlete performance is a 'real' change or not. If the change in performance is within the margin of measurement error, then the practitioner cannot state with certainty that any change in performance has been found.

The Kingcycle has been shown to be a fairly reliable ergometer for exercise testing. Typical error of approximately 3-4% can be expected for tests lasting several hours when using the Kingcycle and decreases to about 2% in tests of around 60 mins (Paton and Hopkins, 2001). While it would seem reasonable to expect typical errors less than 2% in tests lasting around 30 mins, this expectation does not appear to hold true (Paton, unpublished report). In simulated cycling time trials when expressed as mean power output, the variation in CV is likely to range from 1.2% - 4.6% (Hopkins et al., 2001). In a study by Palmer et al. (1996), an exceptionally high correlation was found between a simulated and actual 40-km time trial ($r=0.98$) with a typical error of the estimate of just 1.0% (0.6-2.4%: 95% confidence interval).

An obvious reason for the Kingcycle's reliability is the ability of cyclists to use their own bike, which is known to decrease the random error (Paton and Hopkins, 2001). Also, power output is adjusted for changes in ambient air temperature and pressure "which have considerable effects on air resistance through changes in air density" (Paton and Hopkins, 2001 p. 492).

Choice of Subjects and Timing of Tests

Gore et al. (1996) found S_aO_2 and oxygen content in the blood decrease significantly more in highly trained compared to untrained athletes at just 580m altitude. These findings confirm earlier studies by Lawler et al. (1988) and Terrados (1992), which described greater decreases in VO_{2max} at low and moderate altitudes with trained athletes compared to untrained subjects. These studies provide physiological reasons as to why the subject population needs to be considered and controlled.

From a statistical standpoint, athletes are more reliable during tests to simulate performance compared to non-athletes (Hopkins et al., 2001). Also, increasing the time between tests beyond 2.5 days is likely to result in a corresponding decrease in test reliability, mainly owing to tiredness, fitness or other factors (Hopkins et al., 2001).

Statistical simulations provide some insight as to whether or not an athlete is likely to show a change in performance. Hopkins et al. (1999) examined the medal prospects of top athletes and found that the smallest worthwhile change is about half the random error associated with an athlete (the within-athlete coefficient of variation). Application of this approach to cycling has revealed

that performance improvements (calculated as time) above 0.5% in the Kilo and 0.6% in road time trials will affect the chances of winning in top athletes (Paton and Hopkins, submitted for publication).

Angiotensin Converting Enzyme Gene

It is well known that genetics play a part in determining physical fitness but, until recently, no consistent findings have supported a strong link between genetics and athletic performance (Maes et al., 1996). Montgomery et al. (1998) provided the first credible evidence of such a link in a study of the gene responsible for coding the angiotensin-converting enzyme (ACE) on high-altitude climbers as well as on short-term muscular performance in army recruits. Later, Wolfarth et al. (2000) examined the α_{2a} -adrenoceptor gene, but found a less clear relationship with VO_{2max} . Therefore, this review will focus on the advances that have been made with the ACE gene and how the findings, although not consistent at this point in time, can be related to the pursuit of winning as well as research methodology design.

ACE converts angiotensin I to the vasoconstrictor angiotensin II, both of which are part of the renin-angiotensin system. Angiotensin II has central effects on circulatory control (Montgomery et al., 1998; Cragg, 1989 p. 442) and local skeletal-muscle effects such as glucose uptake in exercise, amino acid uptake, insulin sensitivity, glycogen storage, glucose transporter GLUT-4 synthase activity and adaptation of the enzymes for glucose catabolism (Montgomery et al., 1999).

A polymorphism of the ACE gene has been detected whereby a fragment containing 287 base pairs is either present or absent (Danser et al., 1995). These alleles have been given the abbreviation 'I' (inserted) if present or 'D' (deleted) if not. Humans exhibit either homozygosity (i.e. contain the pairing II or DD) or heterozygosity (i.e. contain the pairing ID) and a typical distribution is 25% for II, 60% for ID and 15% for DD (Montgomery et al., 1997; Montgomery et al., 1999).

In ground-breaking research, Montgomery et al. (1998) showed that 33 British mountaineers, all of whom had climbed beyond 7000m, had significantly different ACE genotype distributions compared to 1,906 British males. Further, of the 15 climbers who had ascended above 8000m (heights above 8000m are often termed the "death zone"), none had the DD genotype. In a second study reported in the same paper, 10 weeks of identical training for 78 male army recruits resulted in significantly greater improvements in the ability to perform bicep curls holding a 15-kg barbell for those of II and ID genotypes. The results, particularly of this second study, gave rise to the notion that the ACE gene could predict "trainability" in athletes.

Williams et al. (2000) had subjects cycle in 3-minute stages to calculate a measure of muscular efficiency before and after an 11-week, primarily aerobic, training programme. Despite non-significant differences in efficiency prior to training, the 35 army recruits with II genotypes exhibited significantly greater improvements in efficiency compared to the 23 recruits with DD genotypes. This study reinforced the idea that the gene could predict "trainability" with short- and long-term muscular activity and possibly in hypoxic situations.

ACE activity has also been associated with myocardial infarction and coronary artery disease (Danser et al., 1995) and is regulated with treatment in such pathological instances (Montgomery et al., 1999). To further examine the role of the ACE genotype in the heart, Montgomery et al. (1997) studied the left-ventricular dimensions of the heart before and after a 10-week intensive strength- and endurance-training period in 140 male army recruits. Pre-training values were not different between subjects of varying ACE genotypes, but the increase in left-ventricular mass (and plasma brain natriuretic peptide, a cardiac hormone associated with left-ventricular growth) was significantly greater in those with the DD genotype compared to those with the II genotype.

In support of Montgomery et al.'s (1997) findings, Folland et al. (2000) showed that nine weeks of strength training produced a significantly greater increase in isometric and dynamic knee extension force production with subjects containing the D allele compared to subjects with the II genotype. Although hypertrophy may not be the sole mechanism pertaining to strength increase, it was suggested, "the ACE genotype that regulates the hypertrophic processes [i.e. the D allele] in other tissues may do likewise in skeletal muscle" (Folland et al., 2000 p. 577).

To somewhat confuse the situation, Woods et al. (2001) showed that subjects with the II genotype had significantly greater improvements in isometric force production compared to those with the DD genotype in subjects receiving hormone replacement therapy. However, cross-sectional muscle area was measured and it was found that the gains were made independent of hypertrophy. Therefore, it is still plausible that the D allele is related to growth.

The reasons why ACE genotype might predict such training responses is unknown, although the most frequent hypotheses involve the skeletal-muscle renin-angiotensin system. The I allele is associated with decreased ACE activity in both plasma and cardiac tissue (Danser et al., 1995). Decreased ACE activity elevates the localised skeletal-muscle effects listed above and, accordingly, have a marked impact on physical activity.

It was not long before the scientific community realised that possible misuses of such genetic information could prove integral in the pursuit of winning performance (Lavin, 1999; Montgomery & Woods, 1999). However, determining subjects' genotypes might also be useful in a research setting when trying to determine why individuals may or may not have responded to a given treatment. In essence, it could be a key consideration when attempting to control all imaginable variables in a research study.

Summary

The live high - train low protocol will probably improve short-term, high intensity, endurance performance at sea level. However, the cost and ability to relocate to a suitable venue makes IHT an attractive alternative. IHT possibly replicates the physiological effects observed during a moderate-altitude training camp and may even elicit a similar peripheral response to a series of 5-min training intervals.

Athletes should probably incorporate IHT for up to five hours per day, for at least nine sessions over a three or four-week period set to simulate altitudes up to 6,000m. Care should be taken to ensure normal protein intake and avoidance of anaemia whilst following a course of IHT. However, only limited scientific studies address IHT and its effect on endurance performance, and no conclusions can be drawn at this stage.

Further scientific studies are needed to describe the effects of IHT. Reliable tests of performance and effort-independent measures, such as blood parameters, are required to determine whether IHT provides benefits to high-calibre athletes over and above placebo. Genetics, such as the genotype for the ACE gene, may help to explain a response.

CHAPTER THREE

Methodology

Subjects

Cyclists were chosen for this study because of their availability and calibre in the Christchurch area. In addition, power in cycling is more-accurately calculated than some other exercise modes and the use of power to monitor performance over time has been shown to be one of the most reliable measurements (Hopkins et al., 2001).

Many of the subjects were recruited over a three-week period by distributing information about the study just before a weekly, 10-km cycling time trial on the outskirts of Christchurch. Some were cyclists that had received services through the Sport Science Centre[®], University of Canterbury in the past. Others were recruited through word-of-mouth via coaches, athletes or doctors known to the researcher.

Information (Appendices A and B) about the aims of the project, participant requirements, use of the results and contact details was provided to all subjects in the recruitment process and no one was coerced or forced to begin the experiment. The subjects were not required to pay for any part of the study and received no incentives or payment for participating. However, most viewed the regular exercise physiology and blood tests as beneficial to their cycling. Those who were to receive IHT were generally eager for a potential enhancement in performance.

Thirty male and eight female highly-competitive participants volunteered to begin the study. They comprised twenty-two cyclists, eleven multi-sport athletes and five triathletes. In almost all cases, subjects were randomly assigned to either the IHT group (those receiving IHT via the Hypoxicator) or the control group (those not receiving IHT), the exception being where a subject's time availability prevented their use of the Hypoxicator.

By the end of the study, eight participants had withdrawn – six in the IHT group (three males and three females) and two in the control group (both males). Reasons included lack of time, injury or relocation from the area. Unfortunately, all three female subjects (including one Olympian) assigned to the IHT group withdrew during the study. Their withdrawal created an unmatched grouping. Therefore, the results of the females in the control group were removed and only the male data will be considered throughout the remainder of this study. Subjects' height, weight, age and VO_2max are presented in Table 2.

Table 2: *Physical characteristics of the subjects who completed the study (mean \pm standard deviation).*

	IHT	Control
	Males (n=12)	Males (n=13)
Height (m)	1.80 \pm 0.04	1.77 \pm 0.07
Weight (kg)	72.1 \pm 6.2	74.7 \pm 9.2
Age (yrs)	26.3 \pm 5.9	32.1 \pm 8.6
VO_2max	70.8 \pm 7.4	64.4 \pm 3.1

Of those who began the study, approximately 23% were competing internationally (including three Olympians), 31% were competing nationally and 46% were competing at club level. However, it is difficult to determine accurate percentages because there is limited regional representative cycling and multi-sport competition.

All subjects were actively competing throughout study. Typical weekly training loads were between seven and twelve hours per week of moderate-hard (subjectively assessed by participants) cycling. Subjects were excluded from participating if under 18 years of age, intending to travel overseas during the course of the study, injured, iron deficient (ferritin < 15µg/L) as determined from the first round of blood testing, ill, with a haematocrit over 54% (males) or 47% (females) or with a VO_2max less than 60ml/kg/min (males) or 50ml/kg/min (females).

A brief summary of subjects' initial requirements (Appendices C and D) was provided immediately prior to the first testing session (a VO_2max test) and subjects were encouraged to ask questions about the study. Informed, written consent (Appendix E) was obtained in accordance with regulations of the Ethics Committee at the University of Otago. This consent was also endorsed by the University of Canterbury Ethics Committee.

Timeline

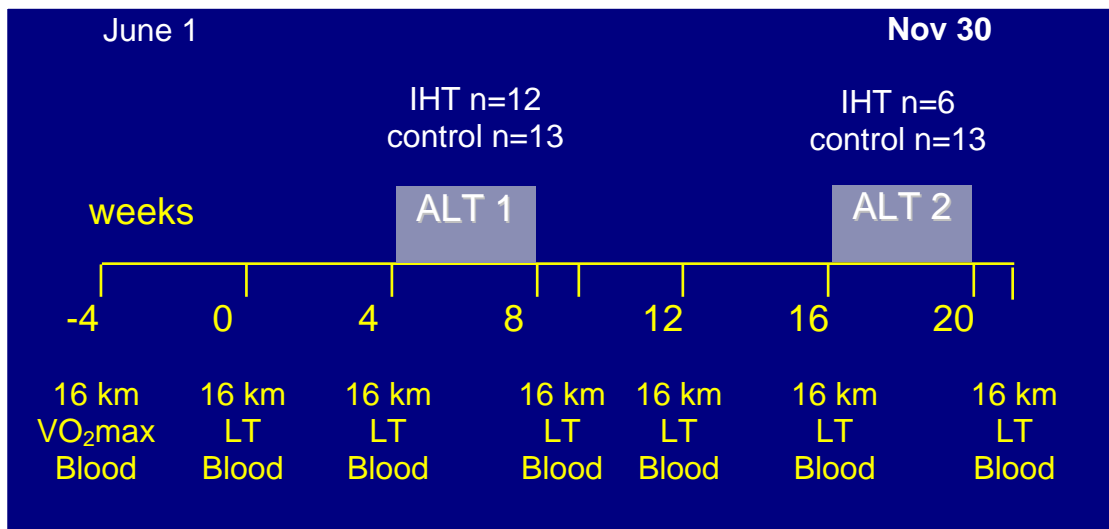
Testing was conducted every four weeks except immediately after using the Hypoxicator, which was four weeks and nine days (Figure 1). A nine-day, post-altitude test period was chosen because it is within the timeframe when the physiological and performance effects have been shown to “peak” following simulated altitude exposure. Additionally, a significant improvement in performance was found 9 days after a simulated-altitude exposure in an unpublished, pilot study at the Australian Institute of Sport (Kim Swannick, personal communication).

Trial one comprised a 16-km time trial familiarisation test and VO_2max for descriptive purposes. Results from the familiarisation test have not been used in presentation and analysis of results. Subjects completed a 16-km time trial (IHT group only), lactate threshold test and blood test for haematocrit and haemoglobin at each subsequent testing session.

The results of trials two and three were compared for reliability and to help characterize the effect of training. Trial four was conducted after the first bout on the Hypoxicator while trials five and six were to track the effect of the Hypoxicator on performance. A final trial was conducted after the second bout on the Hypoxicator.

The subjects' coaches were asked (Appendix F) to bring their cyclist's training into a four-week mesocycle and ensure their fourth week was an easy, "unloading" week immediately prior to testing. Most cyclists were already following a four-week mesocycle and only had to shift the "unloading" week into line with the requirements of the study.

Figure 1. Timeline of the study indicating the periods of exposure to IHT (ALT 1 and ALT 2), the 16-km time trial tests (16km) and blood tests for the IHT and control groups. LT refers to the lactate threshold tests and blood refers to haematocrit and haemoglobin tests.



Training

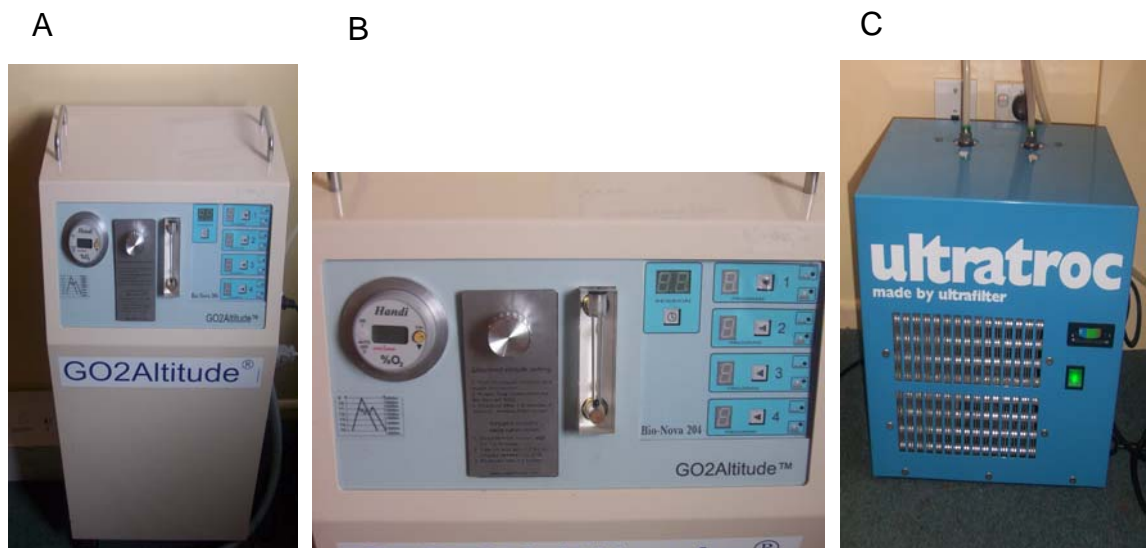
In order to avoid altering cyclists from their normal environment, they were asked to maintain their normal training programme, with only one exception. The subjects' coaches were asked (Appendix F) to bring their cyclists' training into a four-week mesocycle and ensure their fourth week was an easy, "unloading" week immediately prior to testing. Most cyclists were already following a four-week mesocycle and only had to shift the "unloading" week into line with the requirements of the study.

IHT Protocol

The Hypoxicator (Model 2000, GO2 Altitude[®], Biomedtech Australia Pty Ltd, Australia) (Figure 2) is a commercially-available device now found in Christchurch and Auckland at some sport science and sports medicine clinics. It is a stand-alone unit measuring 400 x 300 x 690mm and weighing approximately 25kg. Four, thin, plastic tubes each connect a mask to the central, gas-delivery unit. For safety reasons, masks are held over the mouth and nose and are not fitted to the face. Flow rate and the percent oxygen delivered to the mask ($F_{I}O_2$) are obviously displayed and are manually adjusted with ease. Flow rate ranges from 10-15L/min and $F_{I}O_2$ from 9.5-15% oxygen (simulating an altitude of 2,700-6500m).

The Hypoxicator was housed centrally at Active Health QEII, a sports medicine clinic located approximately 10km from central Christchurch. It was made available to athletes 24 hours per day to assist compliance with the study requirements.

Figure 1. A) The Hypoxicator unit, B) the Hypoxicator control panel, C) the oxygen-extraction unit.



Prior to the study, subjects in the IHT group were provided written and verbal information by a registered nurse familiar with the Hypoxicator regarding the potential health risks associated with the device and inhalation of hypoxic gas. A sports doctor, who was familiar with the practical and medical aspects of altitude training and hypoxic gas inhalation, had briefed the nurse. On their first visit, subjects were taught to use the Hypoxicator and a pulse oximeter and were led through the series of intermittent hypoxic exposures. Subjects were offered further instruction during subsequent visits.

Each visit consisted of alternating the breathing of low-oxygenated air with ambient air in five-minute intervals whilst in a resting state. The $F_{I}O_2$ was selected to elicit a S_aO_2 of 88-92% in week one, 84-88% in week two, 80-84% in week three and 76-80% in week four. S_aO_2 was measured using a pulse oximeter (N-20PA, Nellcor Puritan Bennett, USA). Iron supplements (1 tablet Ferrogradumet twice per day) were taken throughout the simulated-altitude exposure. Subjects were asked to complete five one-hour bouts on the Hypoxicator per week for a four-week period.

Kingcycle Ergometer Testing

Subjects reported to the laboratory for testing on a Kingcycle ergometer (Kingcycle Trainer System version 6.5, Kingcycle, Buckinghamshire, UK) at approximately the same time of day on each occasion to control for the time-of-day variability in some tests (Wyse et al., 1994). Subjects were asked to refrain from alcohol and exercise 24 hours prior to testing, continue with their normal, high-carbohydrate diet 24 hours prior to testing and to avoid caffeine on the day of the test. Fluid was consumed *ad lib* before, during and after testing (except during the VO_2max because of restrictions with the mouthpiece) and a 30-cm, oscillating, 3-speed fan (Model 1231, Mistral, China) was placed in front and just to the right of the cyclist to simulate the air-cooling effect of outdoor cycling. Subjects chose the fan speed.

All testing took place in an indoor, temperature-controlled (20-22°C) laboratory. While relative humidity was not controlled, it was measured before every test and was generally stable between 50-60% as measured by a whirling hygrometer (Casella, London, UK) (Figure 3). Subjects placed their own racing bicycles according to manufacturers instructions onto the Kingcycle ergometer (Figure 4), which was linked to a PC computer (DECpc LPx⁺ 433 dx, Digital, Taiwan). Particular care was taken to check the rear tyre alignment, pressure, dryness and cleanliness. The Kingcycle was chosen because of its accessibility, the familiarity of the device to many of the cyclists (the Kingcycle is specified in Cycling NZ and Triathlon NZ physiology test protocols (Paton, 2000)) and it has been demonstrated to have low random error (Paton and Hopkins, 2001). It is important to note that power output is adjusted for

changes in ambient air temperature and pressure (Equation 1) in the version of software used during the study.

Equation 1. Adjustment of power with varying ambient air pressure and temperature.

$$\text{Power} = (cR^3) (AP/758)(293/(293+AT))$$

where:

$$c = 0.000001172 \text{ (or } 1.172E^{-6})$$

R is the wheel angular speed (revs per minute)

AP is the ambient air pressure (mmHg) and

AT is the ambient air temperature (°C).

Figure 3. Whirling hygrometer used to measure temperature (°C) and relative humidity.

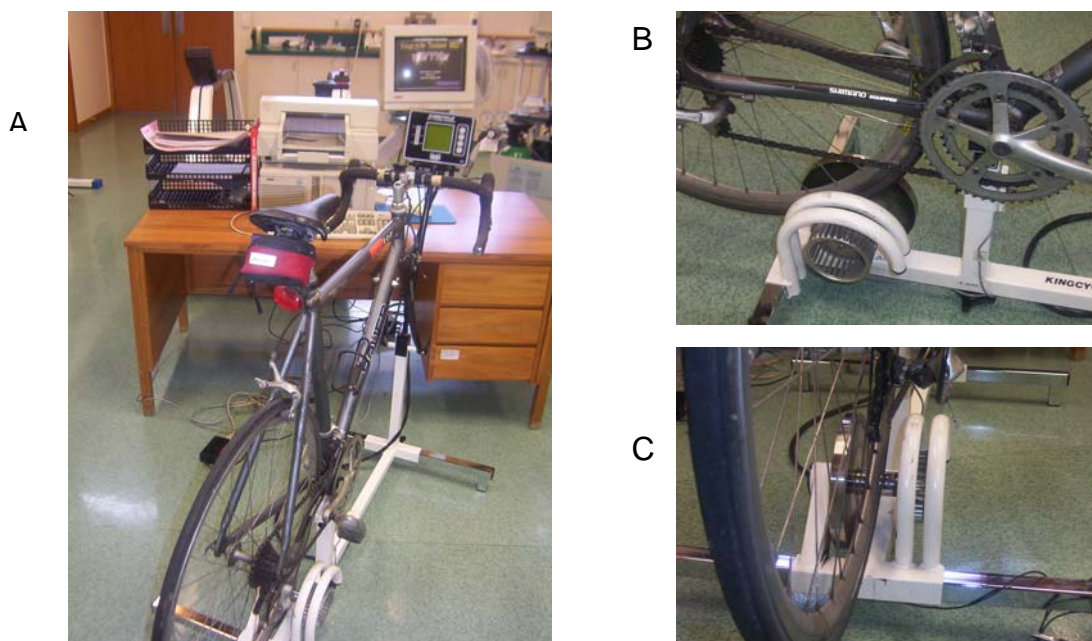


Calibration of the Kingcycle Ergometer

Calibration of the Kingcycle ergometer does not necessarily improve the validity of the power output reading (Paton and Hopkins, 2001). However, calibration should reduce the day-to-day variation in power readings and it involved manually raising or lowering the bottom bracket of the bicycle so that the rear tyre pressure exerted on the flywheel was consistent between tests.

The calibration section of the software leads the calibration process. A power value was entered and the rider accelerated until reaching about 10% greater than the specified calibration power. At this point, subjects were instructed to stop pedalling, assume the cycling position they would adopt for the test and refrain from movement. The bottom bracket was adjusted according to the computer display. The process was repeated (usually once or twice) until the computer display reported that the rear tyre pressure on the flywheel was within an acceptable limit of error.

Figure 4. A) Cycle placed on the Kingcycle ergometer, B) and C) rear wheel attachment to the Kingcycle ergometer flywheel.



VO₂max Testing

The protocol for determining VO₂max was taken from that described by Paton (2000). The Kingcycle ergometer was calibrated at 150W (females) or 250W (males) mid-way through a 10-min warm-up at an individually-determined power output. A heart rate monitor strap was fitted around subjects' chest and heart rate was displayed via a wristwatch (PE1500, Polar, Finland). The subjects' nose was blocked using a nose clip so that all inspired and expired air was channelled through the mouthpiece they were asked to wear. A plastic, micro tube connected to a small hole in the mouthpiece and, with the help of a small vacuum, drew the inspired and expired air into a mass spectrometer (EX670, PK Morgan Ltd, Kent, UK) (Figure 5). Breath-by-breath measures of oxygen and carbon dioxide were analysed and averaged every 15s. A turbine connected to the end of the mouthpiece provided ventilation rates and frequency of breathing to the mass spectrometer. A headset supported the weight of the mouthpiece and turbine.

Figure 5. Mass spectrometer VO₂max testing apparatus.



The mass spectrometer was calibrated for oxygen, carbon dioxide and nitrogen using an automated process. The unit measured firstly a commercially-prepared gas sample ($6.0 \pm 0.1\%$ carbon dioxide, $7.9 \pm 0.2\%$ argon, $15.2 \pm 0.2\%$ oxygen, balance of nitrogen) and secondly ambient air. Ventilatory flow was calibrated following three controlled pumps of a 3L syringe connected to the turbine. An indefinite number of post-calibration samples could be conducted with the 3L syringe to check the accuracy of the calibration. An arbitrary error of $\pm 0.03\text{L}$ was selected to confirm calibration of the turbine. Barometric pressure (mmHg), temperature ($^{\circ}\text{C}$) and relative humidity (%) were entered into the computer to correct for oxygen availability.

Before the test, subjects were measured for height for descriptive purposes (Model 220, Seca, Germany) and weighed in minimal clothing (e.g. cycling strip only) using digital scales (Model 770, Seca, Germany) placed on a 2-cm-thick section of wood resting on a level, linoleum-covered, concrete floor. The test began after a small drink and a minute or so of easy peddling to ensure subjects were comfortable with the apparatus. The initial workrate was set at 100W (females) or 200W (males) and increased in ramp fashion by 33W every 55s. A 5-s interval was given for cyclists to adjust their power output to the next level. Subjects were given extensive encouragement throughout the test, which continued until three of the following occurred: voluntary exhaustion; respiratory exchange ratio (determined as the volume of expired carbon dioxide divided by the volume of oxygen uptake) exceeded 1.1; a plateau in the VO_2 v time graph was achieved; heart rate at age-predicted maximum was achieved, and an inability to maintain power output for more than 20s. For all subjects, the test lasted between six and twelve minutes.

Absolute VO_2max was determined as the highest oxygen uptake reading (which had been averaged over 15s) in litres per minute on the VO_2 v time graph.

Relative VO_2max (expressed as ml/kg/min) was determined by dividing the absolute VO_2max result by body weight and then multiplying by 1000.

16-km Time Trial Testing

The Kingcycle was calibrated mid-way through a 10-min warm-up at an individually-determined power output. The calibration power was set at 100W (females) or 150W (males) for the familiarisation test and then at the mean power of the subject's previous time trial thereafter. The test was self-paced and subjects were permitted to see the distance covered as a percentage of the 16km but were not allowed to view their projected cycling speed, elapsed time or power output. Subjects received verbal encouragement in the second half of the test.

To start the test, subjects accelerated to 30km/h and then stopped pedalling. The test was initiated when the flywheel decayed to 20km/h. The reason for this starting protocol was to prevent slippage of the rear tyre on the Kingcycle flywheel, which occurs during moderately- or highly-explosive starts. Mean power displayed by the computer at the conclusion of the 16-km time trial was recorded.

Lactate Threshold Testing

The Kingcycle was calibrated mid-way through a 10-min warm-up at an individually-determined power output. The calibration power was set at 100W (females) or 150W (males) for the first test and then at the power output corresponding to the fourth interval of the previous test thereafter.

During the test, blood was analysed for lactate concentration. The lactate analyser (1500 Sport, Yellow Springs Instruments Inc, Ohio, USA) (Figure 6) was calibrated prior to each test in line with the automated procedure, which requires zero and 5mmol/L lactate reference points. A 5mmol/L sample check was conducted before each test and testing did not proceed unless the reading was within the manufacturer's specified error limit of ± 0.1 mmol/L.

Subjects began the test at an initial workload of 150W (females), 200W (males) or a power derived to elicit two "baseline" lactate results. "Baseline" refers to the low, steady-state, lactate readings observed prior to the first obvious rise in lactate with increasing intensity. After five minutes of cycling, subjects decelerated to 50W or less for one minute during which at least 25 μ L venous blood was removed via heparinized capillary tube from the index fingertip of the left hand. A 25- μ L sample was then drawn from the capillary tube via pipette (Model 1501, Yellow Springs Instruments Inc, Ohio, USA) and inserted into the lactate analyser according to the manufacturer's instructions.

Subjects increased the workload in each five-minute interval by 25W until a lactate reading of 6mmol/L was reached. A graph of lactate v workload was plotted and a third-order polynomial was fitted to the data. Using the graph, lactate threshold was determined in two manners a) by calculating power output at a lactate reading 3mmol/L above the “baseline” measures and b) by calculating power output at a reading of 4mmol/L.

Figure 6. YSI 1500 Sport Lactate analyser.



Figure 7. Pipette used to inject blood into the lactate analyser.



Blood Testing

Subjects reported to a Southern Communities Laboratory (a group of commercial blood testing laboratories) during the morning of their scheduled blood test. Subjects were asked to avoid exercise prior to the blood collection and maintain the same pre-collection meal on all occasions. Five-ml venous blood samples were drawn from the antecubital vein of the arm by a registered nurse and refrigerated at 4°C until analysis.

A technician at the Southern Communities Laboratory analysed the blood samples. A Coulter analyser (Beckman Coulter®, STKS, Florida, USA) was used for the measurement of the red blood cell count (RBC) and mean cell volume (MCV) by impedance technology as described by Bain (1995, p 28-30). The haematocrit is derived from these parameters using Equation 2. Haemoglobin was derived using a modified cyanmethaemoglobin method at 525nm using the Coulter analyser.

Equation 2. Determination of haematocrit using the Coulter method.

$$\text{Haematocrit} = \frac{\text{MCV} \times \text{RBC}}{1000}$$

where:

MCV = mean cell volume measured in femolitres

RBC = red blood cell count $\times 10^{12}$ measured in litres

Angiotensin Converting Enzyme Genotype Testing

Five-ml venous blood samples were drawn from the arm by a registered nurse and refrigerated at 4°C until analysis. Samples were sent by refrigerated transport to Otago University (Dunedin, New Zealand) where a technician determined the ACE genotype by polymerase chain reaction with three primers to distinguish the ACE insertion/deletion polymorphism.

Training Diaries

Subjects completed short diaries (Appendix G) on a daily basis to record the mode, duration and intensity of all training sessions. To monitor for effects of overtraining, subjective ratings of fatigue at the end of the training session, limb pain at the end of the training session, satisfaction with the training session, sleep and stress were recorded on a 5-point likert scale along with alcohol intake and weight. To check that subjects were maintaining the specified hypoxic protocol, they recorded time on the Hypoxicator, S_aO_2 at the end of a five-minute hypoxic interval and F_iO_2 delivered through the mask. Subjective ratings of breathing hard, nausea and headache were also recorded during sessions on the Hypoxicator using a 5-point likert scale in order to identify potential harmful side effects to the subjects' health. The diaries contained a non-compulsory, qualitative section to record comments.

Statistical Analysis

Data were analysed using the Statistical Analysis System (SAS Institute, Cary, NC) and Microsoft Excel 2000. Least squares means were used in order to account for missing data values. Data were log-transformed (Equation 3) to provide percent changes and were analysed using the repeated-measures modelling method.

The Pearson correlation coefficient was used to determine the linearity between two variables. A one-way ANOVA was used to detect differences between groups for treatment and statistical significance was set at 5%. To estimate individual responses, the typical percent variation of tests within subjects (coefficient of variation) was provided by dividing the mean difference by the standard deviation (Hopkins, 1997).

Uncertainty was expressed in 95% confidence limits and the chance that the results were clinically positive, worthwhile effects were derived according to Hopkins (2002). The smallest, worthwhile effect was assumed to be 1.44% derived by examining the smallest, worthwhile effect in a cycling road time trial. This time trial effect is approximately 0.6% (Paton & Hopkins, submitted for publication) but, because the Kingcycle ergometer provides measurements of power, the effect must be converted from time using a factor of 2.4 (Hopkins et al., 1999).

Measures independent of the effect of training were calculated from the difference between actual and forecasted results. Forecasted data were determined using the Microsoft Excel 2000 statistical function, which determines unknown data from a linear trend line. To form this trend line, each subject's raw data points were incorporated except those immediately after exposure to IHT.

Equation 3. Calculation used to determine the percent change in performance.

$$\% \text{change in performance} = (\log_n \text{performance}_2 - \log_n \text{performance}_1) \times 100$$

Funding

Hypoxicator company representatives funded no part of this study nor took part in planning or implementing the design of the study, except by providing advice concerning the protocol of the hypoxic exposure. This policy protects the study from alleged bias toward results that could be used for commercial gain by the manufacturer.

The study was supported with funding by Sport Science New Zealand and the Doctor Tom Anderson Memorial Trust.

CHAPTER FOUR

Results

Description of Subjects, Training and IHT Exposure

The characteristics of the subjects who completed the study are presented in Table 2. There was no statistically-significant difference ($p>0.05$) between the characteristics between groups except for $\text{VO}_{2\text{max}}$ ($p=0.003$).

Training data arising from the training diaries are presented in Figures 8 to 12. There were no significant differences ($p>0.05$) between the IHT group and the control group at any point of the study for the duration of training (Figure 8), intensity of training (Figure 9), quality of the training session (Figure 10), amount of fatigue experienced at the conclusion of the training session (Figure 11) and amount of limb pain experienced at the conclusion of training (Figure 12). There was no significant difference ($p>0.05$) between the IHT group and the control group at any point of the study for intake of alcohol, subjects' weight, stress or sleep.

The IHT group completed 19.5 ± 1.9 and 17.5 ± 2.9 sessions during the first and second bouts on the Hypoxicator respectively. $F_{\text{I}}\text{O}_2$ and $S_{\text{a}}\text{O}_2$ data are shown in Table 3. Table 4 demonstrates subjective ratings of some potentially detrimental symptoms when using IHT. These effects are breathing hard, nausea and headache.

Effect of IHT on Time Trial Performance

There was a 1.8% increase in mean power output during the 16-km time trial ($-1.8 - 5.6$, 95% confidence interval; $p=0.3$) for the IHT group between the two reliability tests prior to exposure of IHT (Figure 13). Relative to pre-IHT performance, an increase of 3.7% ($0.3 - 7.4$, 95% confidence interval; $p=0.04$) was observed after the first exposure to IHT, representing a 91% chance that this is a clinically positive, worthwhile effect.

There was a general upward trend in performance throughout the course of the study and this trend could be explained by the effect of training. Therefore, accounting for the training effect of each individual across all trials in the study would provide a clearer indication of the true effect of IHT exposure. Adopting this approach, performance after the first exposure to IHT worsened by 0.6% ($-3.0 - 1.9$, 95% confidence interval; $p=0.67$) representing a 5% chance that the effect of exposure to IHT was clinically positive and worthwhile and a 71% chance that the effect was clinically trivial (Table 5).

For the second exposure to IHT, a 0.4% improvement was detected in the mean power output during the 16-km time trial ($-3.9 - 5.0$, 95% confidence interval; $p=0.8$) for the IHT group (Figure 13). This improvement represents a 30% chance that the effect of exposure to IHT was clinically positive and worthwhile and a 52% chance that the result is clinically trivial. After taking into account the training effect, performance improved by 0.3% ($-9.0 - 10.7$, 95% confidence interval; $p=0.93$) representing a 39% chance that the effect of exposure to IHT was clinically positive and worthwhile and a 28% chance that the effect of exposure to IHT was clinically trivial (Table 5). By grouping the

subjects' data for both IHT exposures (to improve statistical power), an overall 0.3% negative effect on performance was determined ($-3.2 - 2.7$, 95% confidence interval; $p=0.83$).

The typical variation in testing (within-subject co-efficient of variation) across all subjects and all trials was 4.3% ($-3.5 - 5.4$, 95% confidence interval). The typical variation in test four (immediately after the first exposure to IHT) was 4.6% ($-2.2 - 7.0$, 95% confidence interval).

Effect of IHT on Lactate Threshold and Blood Parameters

Relative to the control group, a 0.6% ($-3.6 - 5.0$, 95% confidence interval; $p=0.8$) increase in power at lactate threshold was observed by the IHT group relative to the control group after the first exposure to IHT (Figure 14). This result represented a 34% chance that the result was a clinically positive, worthwhile effect and a 49% chance that the result was clinically trivial.

There was an obvious upward trend in the results of the IHT group throughout the course of the study and, as with the 16-km time trial data, this trend could be explained by the effect of training. Accounting for the training effect, performance after the first exposure to IHT improved by 2.1% ($-1.2 - 5.6$, 95% confidence interval; $p=0.21$) relative to the control group. This result represented a 66% chance that the effect of exposure to IHT was clinically positive and worthwhile and a 32% chance that the effect was clinically trivial (Table 5).

After the second exposure, the improvement was 2.0% (-6.7 – 11.5, 95% confidence interval; $p=0.64$) when the effect of training was removed, representing a 55% chance that the result was clinically positive and worthwhile and 24% that the result was clinically trivial (Table 5). The typical variation of testing was 4.0% (3.2 - 5.3, 95% confidence interval).

Similar results were observed when lactate threshold was determined as the power at 4mmol/L (Figure 15). A 0.1% (-4.8 - 5.2, 95% confidence interval; $p=0.97$) increase in power at lactate threshold was observed by the IHT group relative to the control group after the first exposure to IHT. This result indicated a 32% chance the result was a clinically positive, worthwhile effect. When the result was controlled for the training effect, a 4.2% (-0.3 – 8.9, 95% confidence interval; $p=0.06$) increase in performance was found representing an 89% chance that the result was a clinically, worthwhile effect and a 10% chance that the result was clinically trivial (Table 5).

A 2.2% (-7.9 – 13.3, 95% confidence interval; $p=0.66$) increase in performance over and above the training effect was observed by the IHT group relative to the control group after the second exposure. This increase represented a 56% chance that the result was a clinically, worthwhile effect and a 21% chance that the result was trivial (Table 5). The typical error of testing was 4.7% (3.8 - 6.2, 95% confidence interval).

The haematocrit results are presented in Figure 16. Haematocrit dropped by 0.4% (-2.7 - 1.9, 95% confidence interval; $p=0.75$) in the IHT group relative to the control group after the first exposure to IHT indicating an 8% chance that

this result was clinically positive and worthwhile and a 71% chance that the result was trivial (Table 5). Haematocrit increased by 0.3% (-1.9 - 2.6, 95% confidence interval; $p=0.76$) in the IHT group relative to the control group after the second exposure representing a 13% chance the result was clinically positive and worthwhile and an 83% chance the result was clinically trivial (Table 5). There was no obvious effect of training and the typical error of testing was 1.4% (1.2 - 1.7, 95% confidence interval).

Haemoglobin decreased in the IHT group relative to the control group after the first exposure to IHT by 2.4% (-10.0 – 5.2, 95% confidence interval; $p=0.53$) and decreased by 1.3% (-8.7 – 6.1, 95% confidence interval; $p=0.72$) after the second exposure relative to the control group (Figure 17). The chances of a clinically positive, worthwhile effect were 16% and 23% respectively (Table 5). As with the haematocrit results, there was no obvious training effect. Typical error of testing was 4.7% (4.1 - 5.7, 95% confidence interval).

*Effect of IHT Exposure Time on Time Trial Performance
and Lactate Threshold*

Figure 18 demonstrates the relationship between the percent change in 16-km time trial performance before and after exposure to IHT and the amount of exposure to IHT. The correlation ($r=0.37$; $-0.71 - 0.12$, 95% confidence interval) indicates an 87% chance of a clinically-negative effect of IHT exposure time on 16-km time trial performance (Table 6). Figures 19 and 20 also show a moderate negative effect between percent change in power at lactate threshold before and after exposure to IHT and the amount of exposure to IHT, each indicating a 73% chance of a clinically-negative effect (Table 6). When lactate threshold is determined as either 3mmol/L above baseline or at 4 mmol/L, the correlation was -0.27 ($-0.69 - 0.28$, 95% confidence interval).

*Effect of Genotype on Time Trial Performance
and Lactate Threshold*

In Figures 18-20, subjects' data have been represented as their ACE genotype and there is evidence that athletes with the DD genotype were more likely to improve in the performance and lactate threshold tests. There was a 99% chance that the difference in mean percent change in 16-km cycling time trial performance before and after IHT exposure between athletes with DD and II genotypes is clinically positive and worthwhile (Table 7). The chance that the difference between athletes with the DD and ID genotypes is clinically positive and worthwhile is 84%.

The trend toward athletes with the DD genotype responding higher to IHT is similar in the lactate threshold tests (power at 3mmol/L above baseline and power at 4mmol/L). There was an 85-87% chance that the difference in mean percent change in lactate threshold performance after IHT exposure between athletes with DD and II genotypes is clinically positive and worthwhile (Table 7). The chance that the difference between athletes with the DD and ID genotypes is clinically positive and worthwhile is 75-77% (Table 7). For the 16-km cycling time trial and lactate threshold tests, there was more chance that the difference between athletes with the II and ID genotypes was clinically negative or trivial than clinically positive.

Table 3: *Inspired oxygen percentage and oxygen saturation of the blood during four weeks using the Hypoxicator.*

Week	IHT					Within	Between
	Exposure	1	2	3	4	Subject SD	Subject SD
F _I O ₂	1	12.7	12.0	10.9	10.2		
	2	12.6	11.3	10.6	10.4	0.41	0.59
S _a O ₂	1	87.6	85.4	81.2	77.9		
	2	87.9	83.6	81.9	77.5	1.46	1.52

Table 4: *Subjective ratings of breathing hard, nausea and headache while using the Hypoxicator (1=none, 2=low, 3=medium, 4=high, 5=severe).*

Week	IHT					Within	Between
	Exposure	1	2	3	4	Subject SD	Subject SD
Breathing	1	1.84	1.78	1.97	2.18		
	2	1.83	1.84	2.04	1.94	0.40	0.90
Nausea	1	1.33	1.15	1.19	1.17		
	2	1.14	1.25	1.18	1.17	0.18	0.39
Headache	1	1.40	1.13	1.21	1.21		
	2	1.09	1.26	1.09	1.16	1.30	1.54

Table 5: *Chances that the change in test performance, over and above the effect of training, of the IHT group (relative to the control group, except for the 16-km time trial test) before and after two four-week periods of the IHT group receiving exposure to Intermittent Hypoxic Training (IHT) using an Hypoxicator are clinically positive, clinically trivial or clinically negative. The smallest worthwhile change in performance was determined as 1.44% and the level of confidence was set at 95%.*

Test	IHT Exposure	Clinically Positive (% chance)	Clinically Trivial (% chance)	Clinically Negative (% chance)
Change in 16-km Time Trial Performance (IHT group only)	1	5	71	24
	2	39	28	33
Change in Lactate Threshold (determined as 3mmol/L above baseline)	1	66	32	2
	2	55	24	21
Change in Lactate Threshold (determined at 4mmol/L)	1	89	10	1
	2	56	21	23
Change in Haematocrit	1	8	71	21
	2	13	83	4
Change in Haemoglobin	1	16	24	60
	2	23	29	48

Table 6: *Chances that the correlation between exposure time to IHT and the change in test performance of the IHT group (relative to the control group, except for the 16-km time trial test) before and after two four-week periods of the IHT group receiving exposure to Intermittent Hypoxic Training (IHT) using an Hypoxicator is clinically positive, clinically trivial or clinically negative. The smallest clinically worthwhile correlation was assumed to be 0.1 and the level of confidence was set at 95%.*

Correlate with Exposure Time to IHT	Pearson Correlation Coefficient	Clinically Positive (% chance)	Clinically Trivial (% chance)	Clinically Negative (% chance)
Change in 16-km Time Trial Performance (IHT group only)	-0.37	3	10	87
Change in Lactate Threshold (determined as 3mmol/L above baseline)	-0.27	10	18	73
Change in Lactate Threshold (determined at 4mmol/L)	-0.27	9	17	73

Table 7: *Comparison of the change in test performance of the IHT group (relative to the control group, except for the 16-km time trial test) before and after two four-week periods of the IHT group receiving exposure to Intermittent Hypoxic Training (IHT) using an Hypoxicicator as a function of subjects' genotype. The 95% confidence limits and chances that the difference in mean percent changes is clinically positive, clinically trivial or clinically negative have been shown. The smallest worthwhile change in performance was determined as 1.44% and the level of confidence was set at 95%.*

Genotype	Diff. in Mean (%)	p value	95% Confidence Limits		Clinically Positive (% chance)	Clinically Trivial (% chance)	Clinically Negative (% chance)
			lower	upper			
Change in 16-km Time Trial Performance							
DD v II	7.90	0.01	2.3	13.5	99	1	0
DD v ID	3.93	0.18	-2.2	10	81	15	4
II v ID	-3.97	0.17	-10.1	2.1	4	15	81
Change in Lactate Threshold (determined as 3mmol above baseline)							
DD v II	4.85	0.20	-3.3	13	83	12	5
DD v ID	3.89	0.38	-5.9	13.7	71	17	12
II v ID	-0.97	0.79	-9.2	7.2	26	29	45
Change in Lactate Threshold (determined at 4mmol)							
DD v II	5.15	0.17	-3.0	13.3	85	11	5
DD v ID	4.30	0.34	-5.7	14.3	74	15	11
II v ID	-0.85	0.81	-8.6	6.9	26	31	43

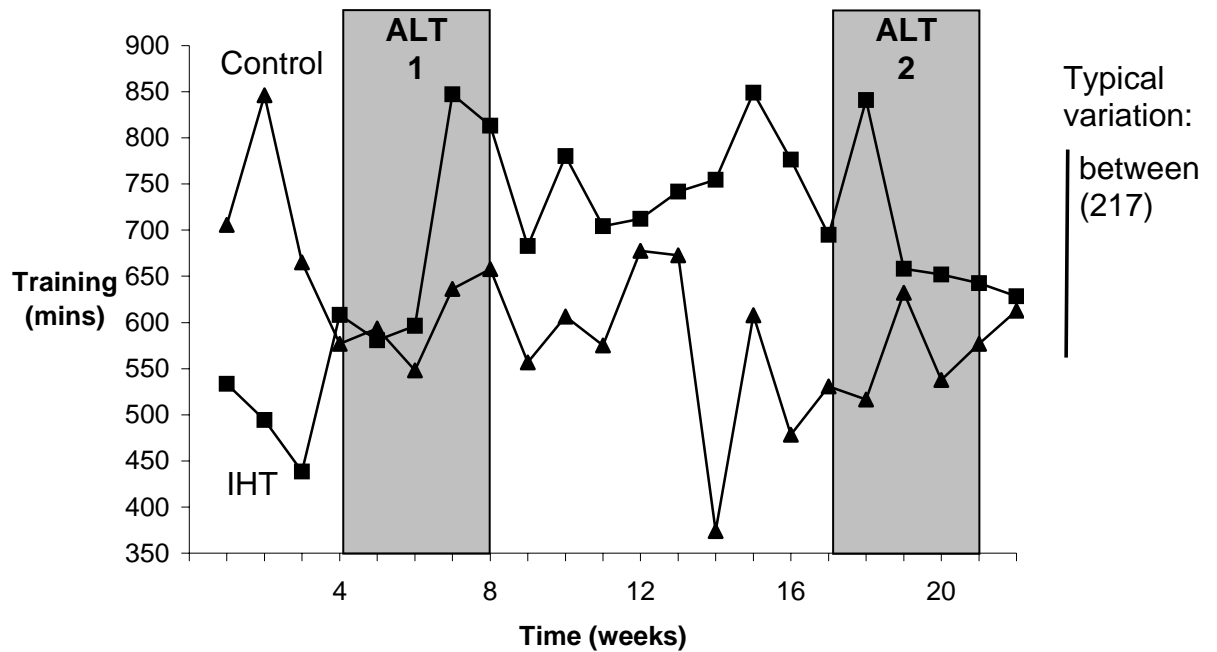


Figure 8. Mean weekly training duration for the IHT and control groups before, during and after two four-week periods of the IHT group receiving exposure to Intermittent Hypoxic Training (IHT) using an Hypoxicator. Data for each of the two IHT exposures are referred to as ALT 1 and ALT 2. Typical variation is between-subject co-efficient of variation calculated across all subjects and tests and shown in minutes. There was slight discontinuity in the timing of athletes entering the second exposure to IHT and data are represented as an additional week.

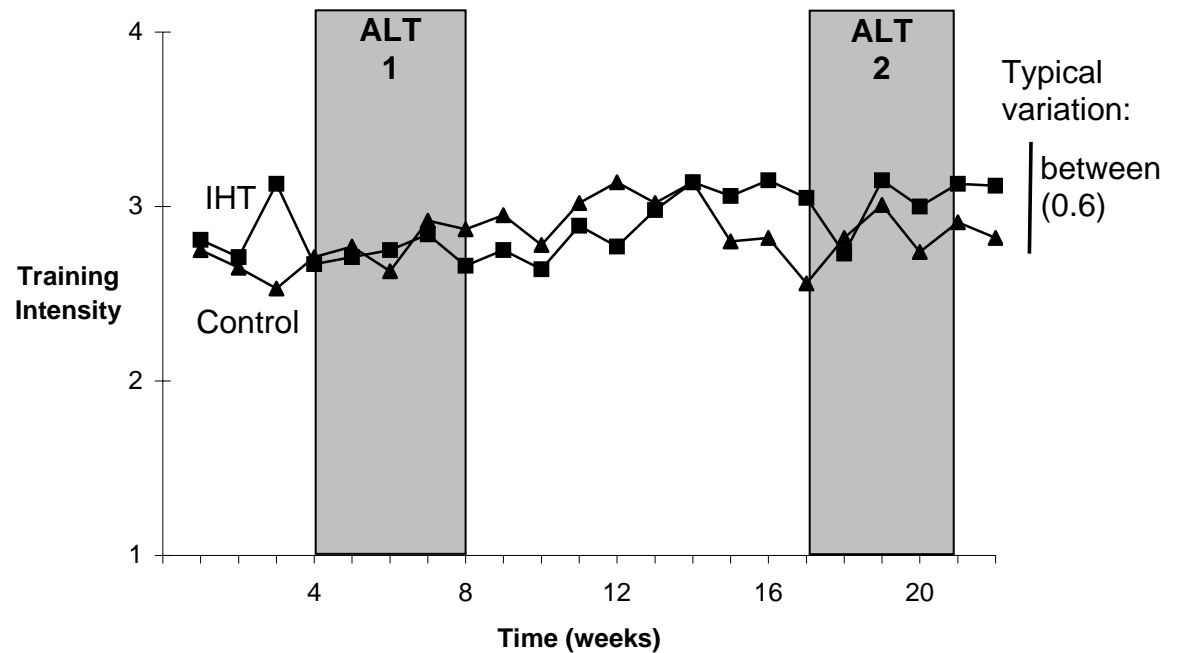


Figure 9. Mean perceived rating of training intensity recorded at the conclusion of each training session on a scale 1-5 (1=easy, 2=steady, 3=moderate-hard, 4=hard, 5=very hard) for the IHT and control groups before, during and after two four-week periods of the IHT group receiving exposure to Intermittent Hypoxic Training (IHT) using an Hypoxicator. Data for each of the two IHT exposures are referred to as ALT 1 and ALT 2. Typical variation is between-subject co-efficient of variation calculated across all subjects and tests and shown in absolute terms. There was slight discontinuity in the timing of athletes entering the second exposure to IHT and data are represented as an additional week.

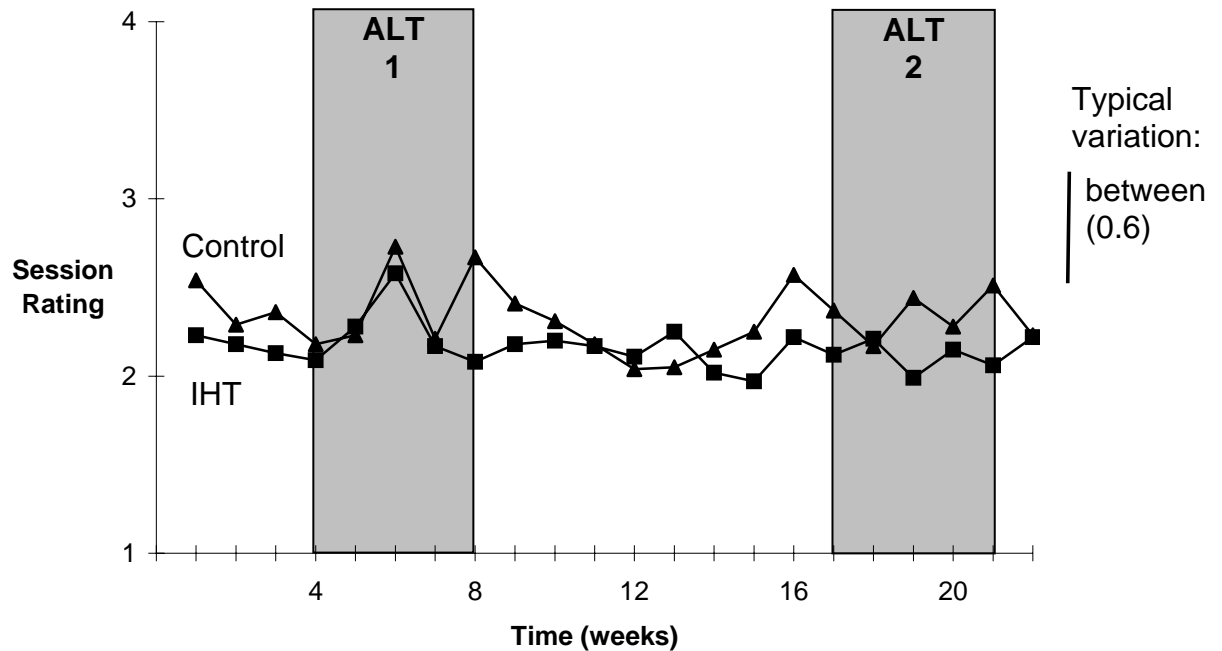


Figure 10. Mean perceived rating of session quality recorded at the conclusion of each training session on a scale 1-5 (1=very good, 2=good, 3=average, 4=bad, 5=very bad) for the IHT and control groups before, during and after two four-week periods of the IHT group receiving exposure to Intermittent Hypoxic Training (IHT) using an Hypoxicator. Data for each of the two IHT exposures are referred to as ALT 1 and ALT 2. Typical variation is between-subject co-efficient of variation calculated across all subjects and tests and shown in absolute terms. There was slight discontinuity in the timing of athletes entering the second exposure to IHT and data are represented as an additional week.

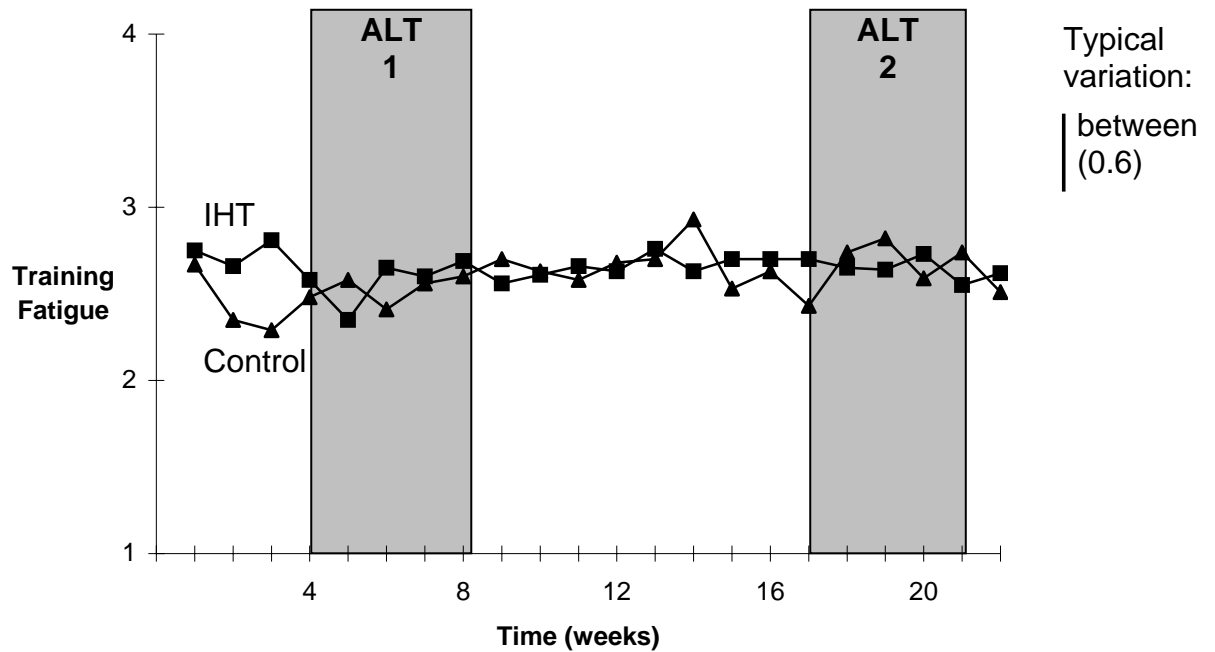


Figure 11. Mean perceived rating of fatigue levels recorded at the conclusion of each training session on a scale 1-5 (1=none, 2=low, 3=medium, 4=high, 5=severe) for the IHT and control groups before, during and after two four-week periods of the IHT group receiving exposure to Intermittent Hypoxic Training (IHT) using an Hypoxicator. Data for each of the two IHT exposures are referred to as ALT 1 and ALT 2. Typical variation is between-subject co-efficient of variation calculated across all subjects and tests and shown in absolute terms. There was slight discontinuity in the timing of athletes entering the second exposure to IHT and data are represented as an additional week.

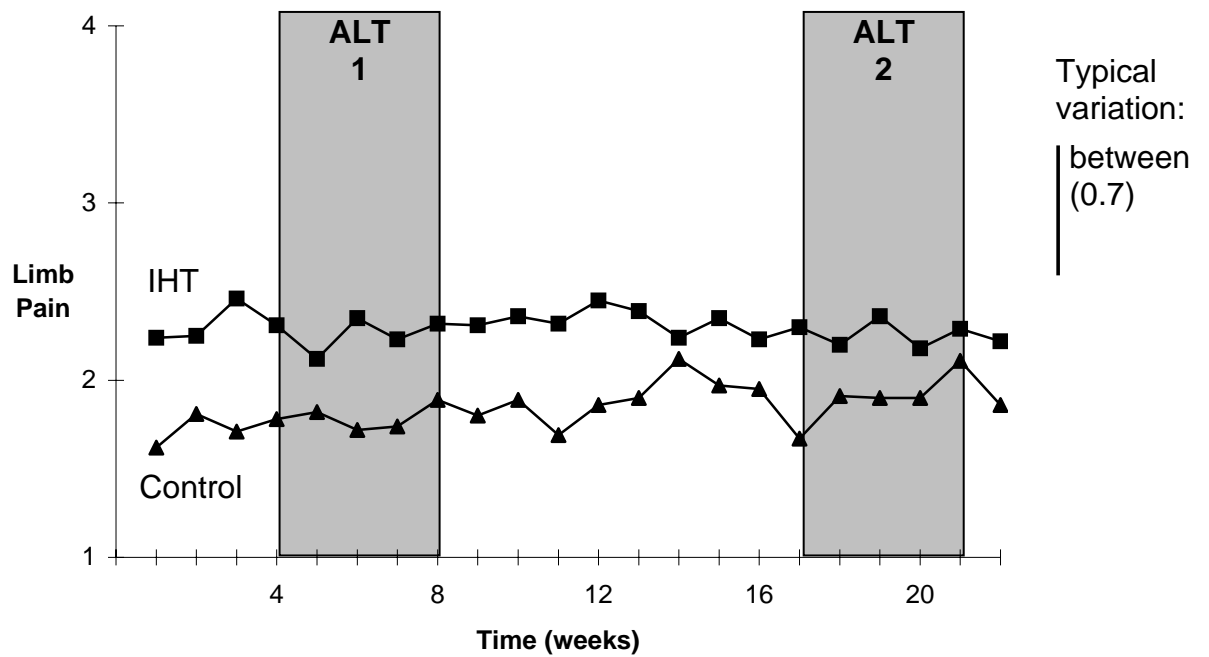


Figure 12. Mean perceived rating of limb pain recorded at the conclusion of each training session on a scale 1-5 (1=none, 2=low, 3=medium, 4=high, 5=severe) for the IHT and control groups before, during and after two four-week periods of the IHT group receiving exposure to Intermittent Hypoxic Training (IHT) using an Hypoxicator. Data for each of the two IHT exposures are referred to as ALT 1 and ALT 2. Typical variation is between-subject co-efficient of variation calculated across all subjects and tests and shown in absolute terms. There was slight discontinuity in the timing of athletes entering the second exposure to IHT and data are represented as an additional week.

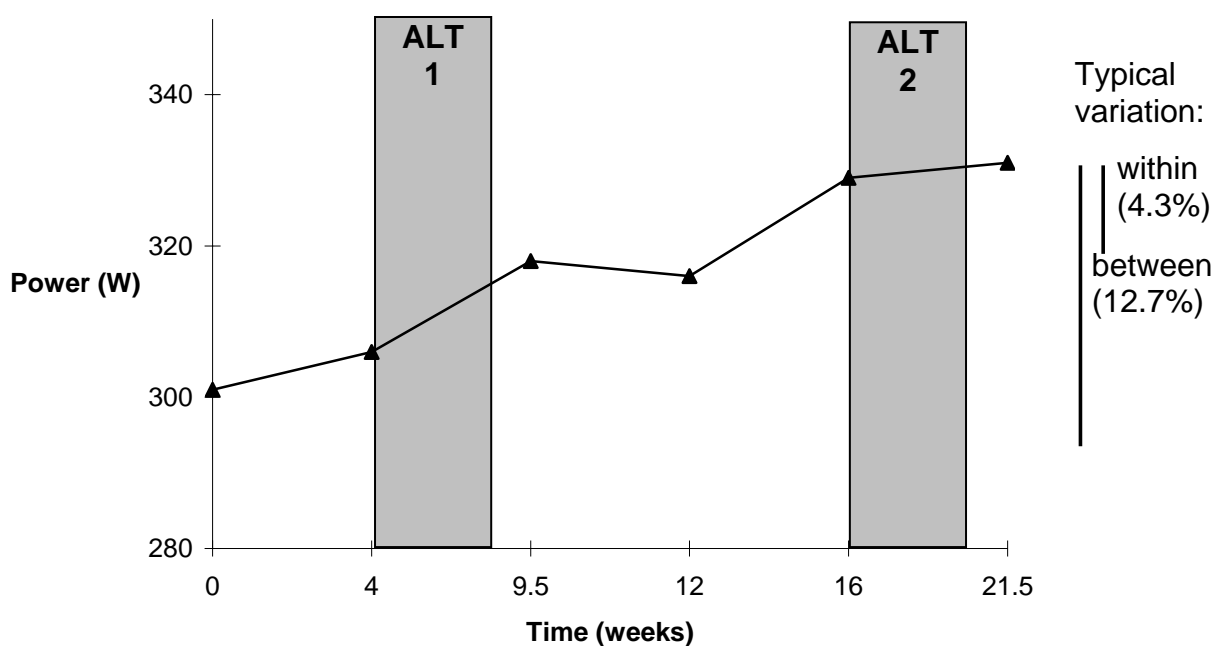


Figure 13. Mean power output during a 16-km time trial (IHT group only) simulated on a Kingcycle ergometer for the IHT group before and after two four-week periods of the IHT group receiving exposure to Intermittent Hypoxic Training (IHT) using an Hypoxicator. Data for each of the two IHT exposures are referred to as ALT 1 and ALT 2. Typical variations are within-subject co-efficient of variation and between-subject co-efficient of variation calculated as percentages across all subjects and tests.

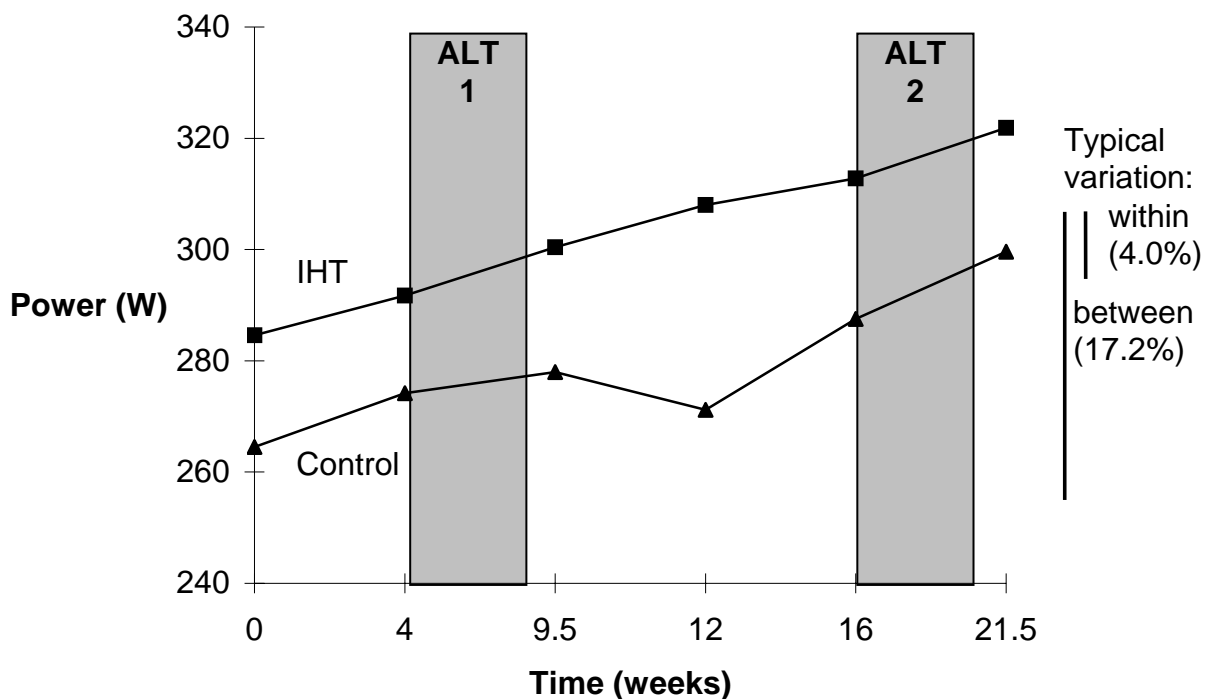


Figure 14. Mean power output at lactate threshold (determined as 3mmol/L above baseline) for IHT and control groups before and after two four-week periods of the IHT group receiving exposure to Intermittent Hypoxic Training (IHT) using an Hypoxicator. Data for each of the two IHT exposures are referred to as ALT 1 and ALT 2. Typical variations are within-subject co-efficient of variation and between-subject co-efficient of variation calculated as percentages across all subjects and tests.

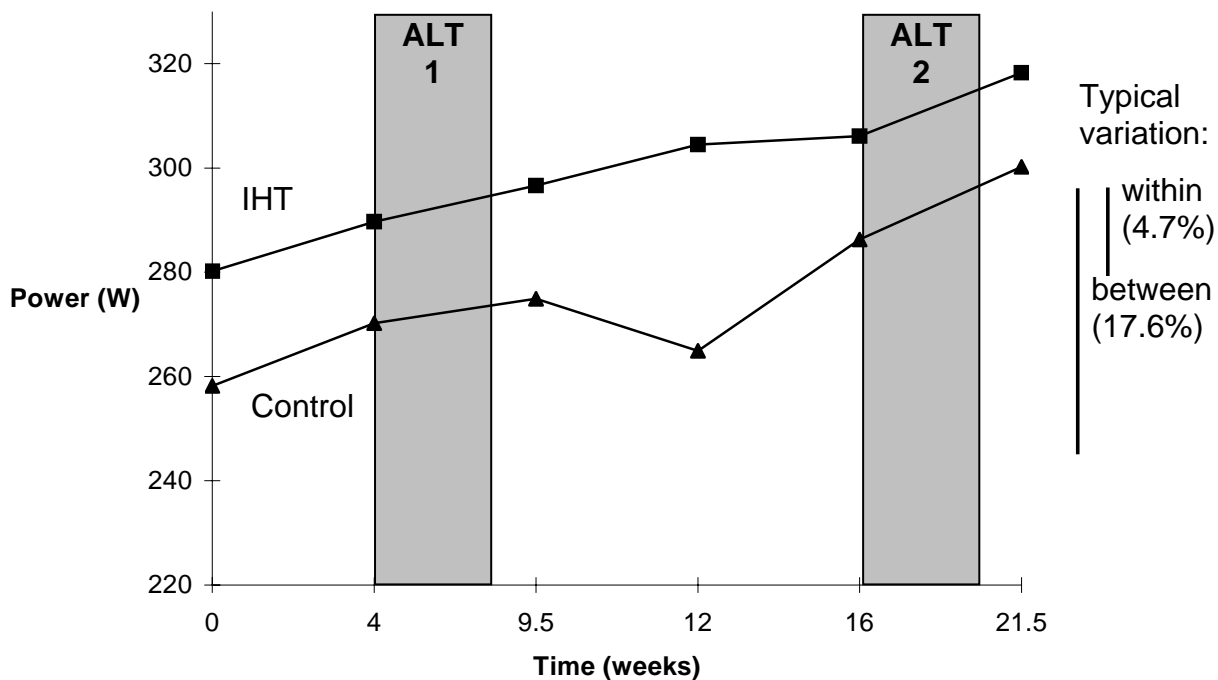


Figure 15. Mean power output at lactate threshold (determined at 4mmol/L) for IHT and control groups before and after two four-week periods of the IHT group receiving exposure to Intermittent Hypoxic Training (IHT) using an Hypoxicator. Data for each of the two IHT exposures are referred to as ALT 1 and ALT 2. Typical variations are within-subject co-efficient of variation and between-subject co-efficient of variation calculated as percentages across all subjects and tests.

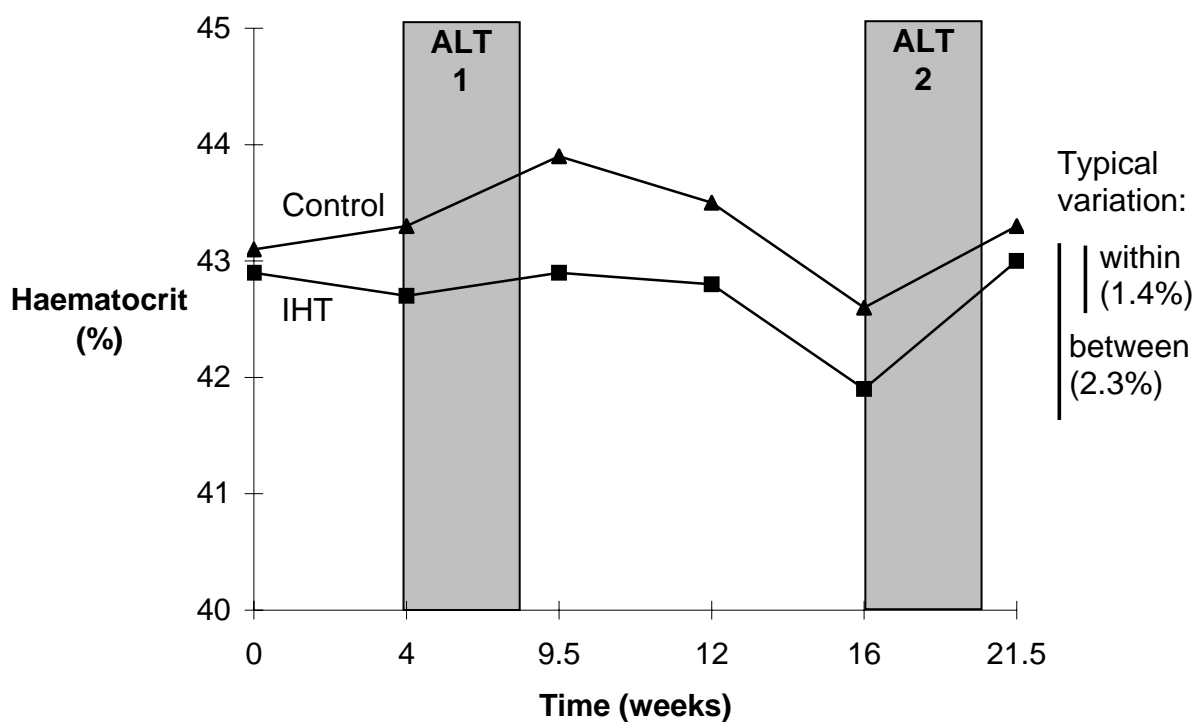


Figure 16. Haematocrit for IHT and control groups before and after two four-week periods of the IHT group receiving exposure to Intermittent Hypoxic Training (IHT) using an Hypoxicator. Data for each of the two IHT exposures are referred to as ALT 1 and ALT 2. Typical variations are within-subject co-efficient of variation and between-subject co-efficient of variation calculated as percentages across all subjects and tests.

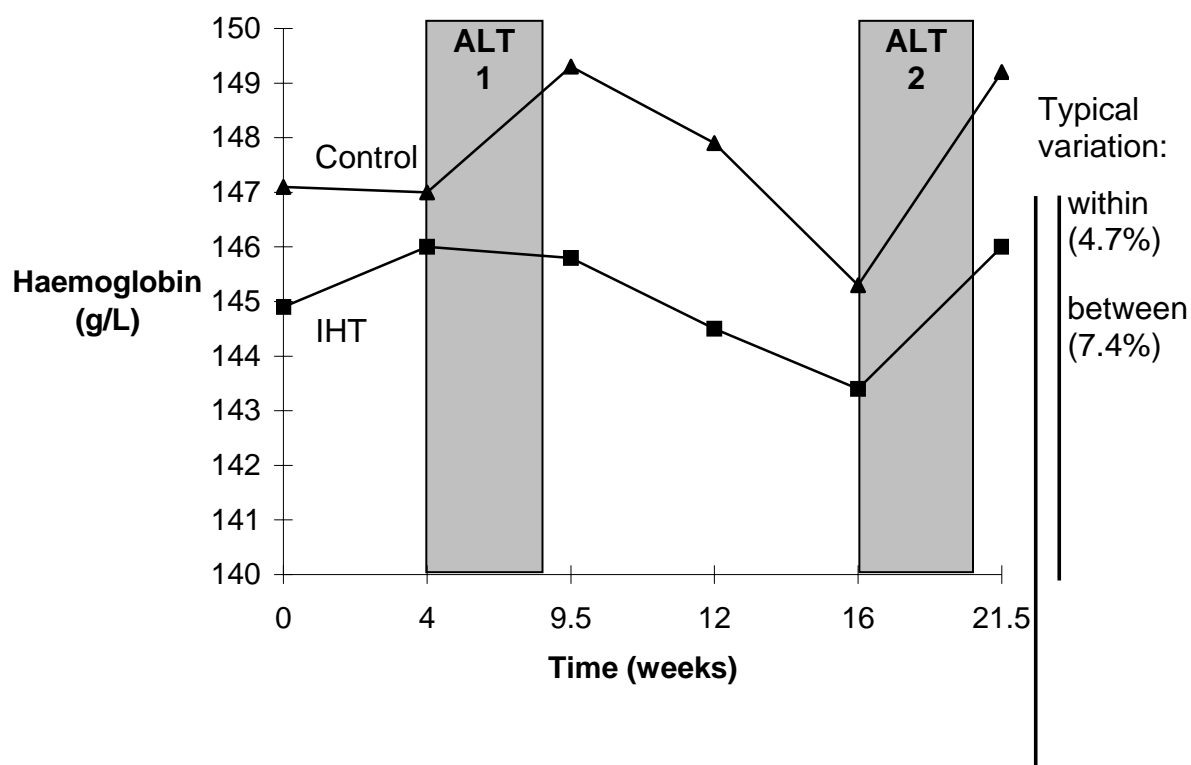


Figure 17. Haemoglobin for IHT and control groups before and after two four-week periods of the IHT group receiving exposure to Intermittent Hypoxic Training (IHT) using an Hypoxicator. Data for each of the two IHT exposures are referred to as ALT 1 and ALT 2. Typical variations are within-subject co-efficient of variation and between-subject co-efficient of variation calculated as percentages across all subjects and tests.

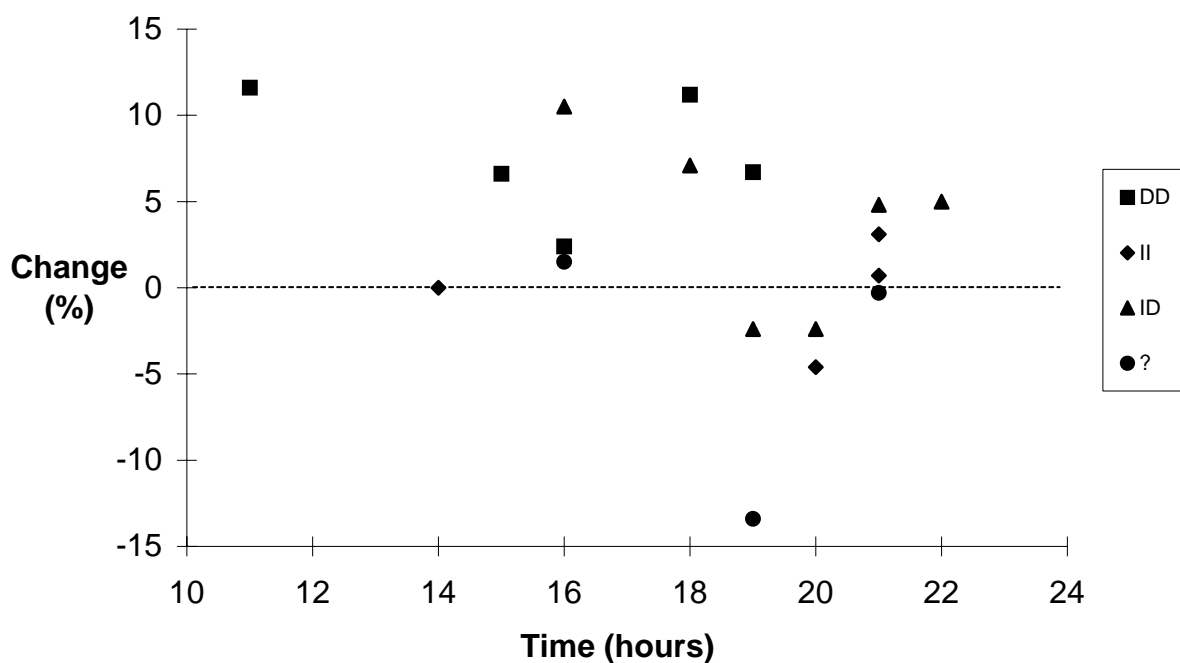


Figure 18. Percentage change in mean power output during a 16-km time trial (IHT group only) before and after receiving exposure to Intermittent Hypoxic Training (IHT) using an Hypoxicator as a function of exposure time to IHT. Data during each of the two IHT exposures have been combined. Each symbol represents one subject and their genotype for the Angiotensin Converting Enzyme gene. The symbol “•” on the graph indicates the genotype for that subject is unknown.

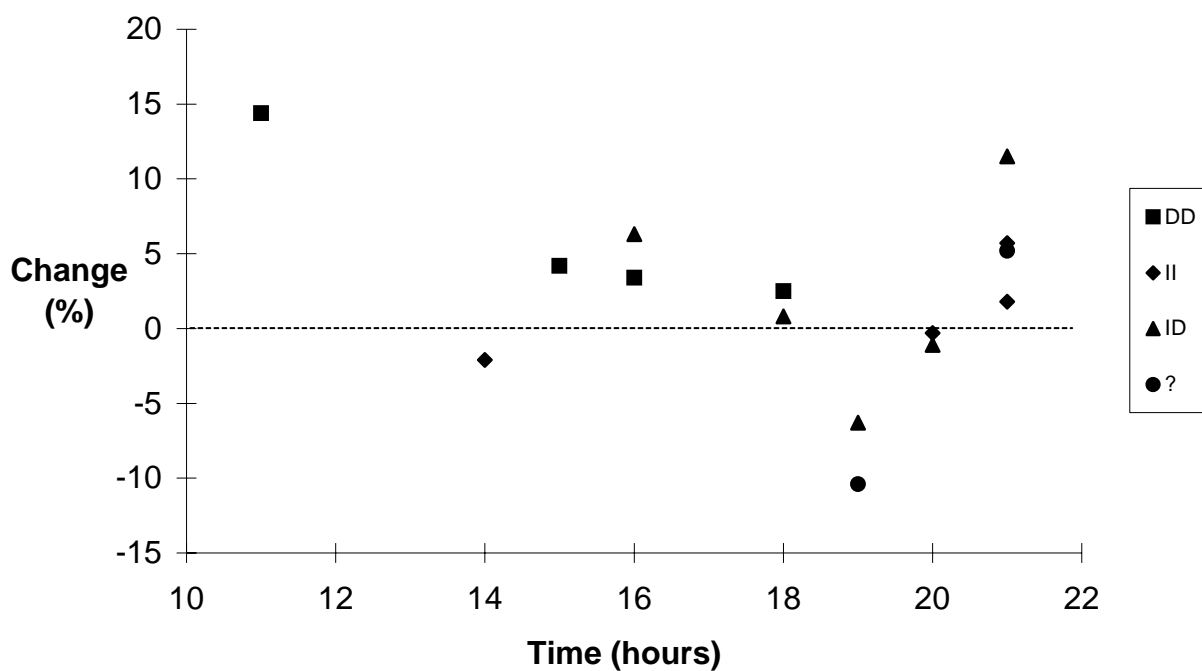


Figure 19. Percentage change in mean power output at lactate threshold (determined as 3mmol/L above baseline) (IHT group only) before and after receiving exposure to Intermittent Hypoxic Training (IHT) using an Hypoxicator as a function of exposure time to IHT. Data during each of the two IHT exposures have been combined. Each symbol represents one subject and their genotype for the Angiotensin Converting Enzyme gene. The symbol “•” on the graph indicates the genotype for that subject is unknown. There are three missing values due to sample contamination.

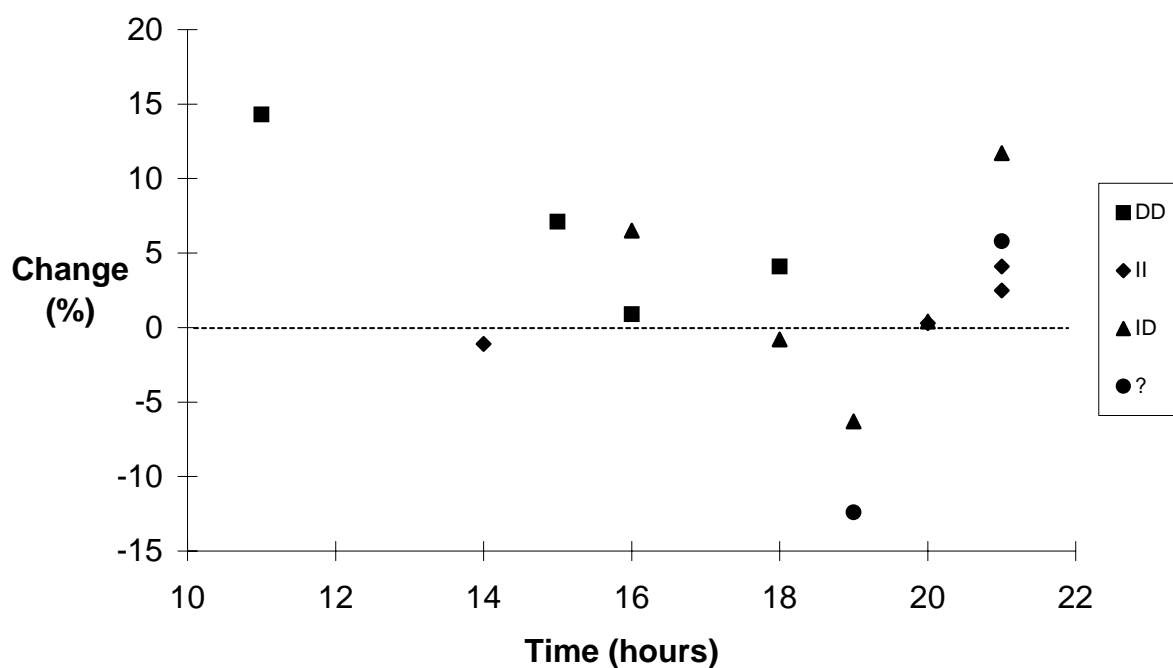


Figure 20. Percentage change in mean power output at lactate threshold (determined at 4mmol/L) (IHT group only) before and after receiving exposure to Intermittent Hypoxic Training (IHT) using an Hypoxicator as a function of exposure time to IHT. Data during each of the two IHT exposures have been combined. Each symbol represents one subject and their genotype for the Angiotensin Converting Enzyme gene. The symbol “•” on the graph indicates the genotype for that subject is unknown. There are three missing values due to sample contamination.

CHAPTER FIVE

Discussion

The Effect of IHT on Time Trial Performance

Many studies have examined the effect of a two-four week training camp at moderate altitude on sea-level endurance performance. The results have been conflicting, with some studies showing an enhancement in performance (e.g. Daniels and Oldridge, 1970; Mizuno et al., 1990; Mittila and Rusko, 1996) while others have shown that performance declines (e.g. Levine and Stray-Gundersen, 1991; Jensen et al., 1993; Rusko, 1996). More recently, a well-designed study by Levine and Stray-Gundersen (1997) found a 1-2% improvement in aerobic performance following a practice they termed “live high - train low”. This practice involved living at moderate altitude but training daily at low altitude thereby maintaining training quality. While 1-2% improvement in performance seems small, in international competition it is often the difference between being a medallist or a non-medallist.

Results have been contrasting in studies addressing the effect of IHT on performance. Clark et al. (1999) found no change in rowing performance or blood parameters, while Hellemans (1999) reported a 2.9% performance improvement. Hellemans' (1999) observation was supported by rises in haemoglobin by 4.3%, haematocrit by 5% and reticulocytes by 30.3%. Unfortunately, this pilot study did not contain a control group and the training effect and test reliability were not determined. Altitude exposure using a protocol similar to IHT has resulted in a 3.9% performance improvement in non-

competitive subjects with a corresponding right-shift in lactate threshold (Rodriguez et al., 1999).

In the present study, subjects demonstrated a 3.7% improvement in mean power during a 16-km time trial performance nine days after the first exposure to IHT (Figure 13). Performance declined slightly four weeks after coming off IHT and then surged again (4.2%) at week eight. The magnitude of the improvement immediately after IHT exposure seems to be in keeping with previous studies, the increase was statistically significant and there is a 96% chance that this result is clinically positive. On the surface, IHT might be described as an exciting, performance-enhancing practice, particularly when Paton and Hopkins (submitted for publication) ascertained the smallest, worthwhile effect to be 0.6% in units of time (1.44% in units of power) or around half the coefficient of variation in testing (Hopkins et al., 1999).

The 'true' effect of IHT needs to be considered in context of the typical error in measurement (also referred to as the random error) relating to the subjects, the Kingcycle ergometer and a time-trial test. In previous studies, this error has been in the order of 2-4% (Paton and Hopkins, 2001). In this study, it was found to be 4.3%. This magnitude of error is higher than the 3.7% increase in performance attributed to IHT. Therefore it cannot be stated for sure that IHT has created a 'true' enhancement in performance.

The magnitude of random error in this study was disappointingly high. Reasons for the poor reliability may have been due to the inability of some athletes to refrain from exercise 24 hours prior to testing or that the regional and club athletes were less reliable (Hopkins et al., 2001). It could also have been that the four-week period separating the reliability trials was too long and that some re-learning took place at the second trial. Hopkins et al. (2001) stated that increasing the time between tests beyond 2.5 days is likely to result in a corresponding decrease in test reliability.

The training effect must also be accounted for in order to determine whether a 'true' change in performance has taken place. When this effect was removed, the change in performance decreased by 0.6% after the first IHT exposure representing just a 5% chance that the IHT exposure created a clinically positive, worthwhile effect.

The result of the second exposure to IHT (Figure 13) supports the notion that IHT does not improve endurance performance and that there is no additional, cumulative effect of repeated exposures to IHT as has been proposed anecdotally with moderate altitude training camps. Subjects showed just a 0.3% improvement in time-trial performance over and above the training effect and, while there was a 47% chance that the effect was clinically positive, there was also a 41% chance it was clinically negative (Table 5).

It should be highlighted that the change in performance after the second exposure to IHT did not appear to increase beyond that of the first exposure (Figure 13) yet the overall effect was greater. The reason for this observation stems from the fact that the training effect was determined in each individual. Obviously the training effect was not as marked in the athletes who completed both exposures.

Of the eighteen subjects assigned to the IHT group at the beginning of the study, only six subjects completed the second exposure to IHT. Such low subject numbers did not assist the statistical power at this point of the study. To address the poor statistical power, the results of both exposures of IHT were combined (18 data points) and no additional evidence for an improvement in performance was found.

If IHT had a causal effect on performance in the 16-km time trial, subjects who received the greatest exposure to IHT should also have demonstrated the greatest improvement in performance. This relationship is shown in Figure 18 and Table 6 and the poor correlation does not support this notion. In fact, there was an 87% chance that the exposure to IHT results in a clinically negative effect on performance.

In summary, IHT exposure probably does not provide a clinically positive, worthwhile effect on 16-km time trial performance nine days after completing the IHT exposure. Similar findings were observed after a second exposure to IHT and on consideration of the amount of time that subjects were exposed to IHT.

The Effect of IHT on Lactate Threshold and Blood Parameters

In this study, subjects were not blinded to the normoxic or hypoxic treatment they received. Therefore, a possible placebo effect could have occurred within the IHT group. To control for the placebo effect and the fact that subjects were not blinded to which treatment they received, tests independent of effort and motivation were conducted. These measures were cycling power at lactate threshold, haematocrit and haemoglobin. The subjects could not unduly influence any of the three measures, which all have been shown to improve as a result of altitude training (Faulkner et al., 1967; Bender et al., 1989; Wolfel et al., 1991; Burglund, 1992; Ingjer and Myhre, 1992; Burtcher et al., 1996; Friedmann et al., 1999; Rodriguez et al., 1999).

A gradual improvement in lactate threshold (determined as either 3mmol/L above baseline or at 4mmol/L) through training was observed in both groups throughout the study (Figures 14 and 15). This training effect was removed to identify the true change in lactate threshold in response to IHT exposure. There was some evidence of a possible additional improvement in the IHT group relative to the control group after exposure to IHT but this observation was not consistently detected. The random test error was higher than expected (Pfitzinger and Freedson, 1998) and this variation would have detracted from determining a more clear-cut result.

Overall, haematocrit and haemoglobin results tended to rise in the IHT group as a result of exposure to IHT (Figures 16 and 17). However, the control group also demonstrated this trend at the same time the IHT group received IHT exposure (highlighting the importance of including a control group for effort-independent measures). The results of previous studies on IHT (Clark et al., 1999; Hellemans, 1999) have been conflicting so it is not surprising that the IHT group did not display higher haematocrit and haemoglobin results relative to the control group following IHT.

In studies examining the live high – train low protocol using simulated altitude, the haematological parameters have also varied (Vallier et al., 1996; Ashenden et al., 1999a; Ashenden et al., 1999b; Rodriguez et al., 1999). Studies using “real” altitude tend to show more clear-cut increases (Ingjer and Myhre, 1992; Savourey et al., 1996; Bonning et al., 1997).

In summary, lactate threshold, haematocrit and haemoglobin have been shown in previous studies to change during an altitude training camp. In this study, the results provided little evidence to support the notion that exposure to IHT improves high-intensity endurance performance. Therefore, it can also be postulated that any improvement in 16-km time trial performance was probably a placebo effect (Clark et al., 2000).

In this study, we did not attempt to control the training regime of the subjects. The reason for this approach stems from the inability of these high-performance athletes to adhere to a 24-week training programme that they could not control, particularly if competing during the course of the study. It could also be argued

that the validity of the study to the practical setting is enhanced when athletes follow their normal training routine rather than a schedule that may be unfamiliar. Therefore, it was postulated that the number of subjects recruited to the study would be sufficient to prevent a difference in training between groups throughout the study.

Figures 8 to 12 show that there was no statistical difference between the groups at any point in the study with respect to training duration, intensity, quality, fatigue and limb pain. Therefore, differences in training can be ruled out as an explanation to why the IHT group did not enhance their performance following exposure to IHT. Signs of overtraining were not significantly different between groups at any point in the study as indicated by measures of training quality, training fatigue, limb pain, weight and sleep.

There is an uncharacteristic drop in training duration in the control group at week 14. Training intensity and session rating do not appear to change unusually but limb pain and fatigue is at the highest point of the study. A probable explanation for these observations is that subjects were involved in important competition at some point during this week.

The within-subject coefficient of variation (a measure of random error) for performance in the 16-km time trial was greatest nine days following the end of the first exposure to IHT. A greater spread of results provides some evidence that there may have been high and low responders to IHT, although wide confidence intervals do not make this finding clear cut. This observation may be explained by a probable improvement in performance in subjects with the

DD genotype (Figures 18 to 20; Table 7). Compared to the pre-IHT exposure, all these subjects improved in their 16-km time trial and lactate threshold tests irrespective of the amount of IHT treatment they received while there was both improvement and decrement in those with other genotypes. Across the 16-km cycling time trial and lactate threshold tests, the difference between athletes with the DD genotypes was 71-99% likely to be a clinically positive result compared to those with the II and ID genotypes (Table 7).

The probable improved response to IHT by subjects with the DD genotype supports the findings of more-recent studies addressing the relationship between performance and the ACE gene (Montgomery et al. 1997; Folland et al., 2000). However, Folland et al. (2000) related these findings to the notion that the D allele may regulate hypertrophic responses in skeletal muscle. Given the endurance training completed by the subjects in this study substantial hypertrophy would not be expected. Reasons for subjects with a DD genotype responding to the IHT exposure are unknown but could support a belief that the ACE gene cannot predict “trainability” or performance. Evidence for this hypothesis comes from the inconsistency in the literature as to which allele is most advantageous (Montgomery et al., 1998; Folland et al., 2000; Woods et al., 2001).

Limitations of the Study

The limitations to this study may have been responsible for an inability to detect a performance enhancement following exposure to IHT. The lack of a control group for the 16-km time trials would have decreased the statistical power but the reasons for not including a control group were two-fold. Firstly, subject blinding to the experimental dose is impossible with simulated altitude because the physiological effects experienced during a session e.g. lowered S_aO_2 make subjects aware of the treatment they are receiving. It was therefore possible that athletes in the control group, knowing they were not receiving a potentially performance-enhancing treatment, would not push themselves to maximal effort. The disparity could have allowed the IHT group's performance to be inflated when their results were compared to the control. Secondly, the possibility of a placebo effect was high in subjects receiving IHT. The use of measures independent of subject motivation and effort (lactate threshold, haematocrit and haemoglobin) were used to account for this effect.

It would have been advantageous to control for protein intake either by prescribing or monitoring daily intake. Protein intake has been shown to be important for EPO production (Berglund, 1992), which is a key regulator of erythropoiesis. In addition, measures of blood volume would have more accurately determined haematocrit and haemoglobin levels. Rises in these blood parameters can be offset with proportional rises in plasma volume (Berglund, 1992; Friedmann et al., 1999) and a performance enhancing effect is concealed.

A 3-15% rise in haematocrit and haemoglobin was expected in light of previous altitude and simulated-altitude studies addressing haematological changes (Faulkner et al., 1967; Berglund, 1992; Ingjer and Myhre, 1992; Stray-Gundersen et al., 1993; Rusko, 1996; Hellemans, 1999; Rodriguez et al., 1999). Both parameters have been shown to improve $\text{VO}_{2\text{max}}$ and endurance performance (Mairbaurl, 1994; Ekblom, 1996; Gore et al., 1997). The lack of change in blood parameters in this study would suggest that IHT does not replicate the haematological adaptations found at altitude and may in part account for the unlikely worthwhile improvement in time trial performance.

While no haematological change was found in this study, it is still possible that adaptations may have taken place at the peripheral level. The few studies addressing muscle morphology and metabolic enzyme activity have reported changes in some parameters, most noticeably myoglobin content, citrate synthase activity and fibre capillarisation (Melissa et al., 1997; Terrados et al., 1988). Improvements in these parameters will assist the delivery and utilisation of oxygen in mitochondrial respiration. Muscle biopsies were not taken in this study so peripheral changes cannot be ruled out despite the lack of change in time-trial performance.

Elite athletes have been shown to decrease S_aO_2 to a greater level than untrained subjects during intense aerobic exercise (Williams et al, 1986). The athletes in this study carry out this sort of training on a regular basis. Assuming that decreased S_aO_2 corresponds to lower muscular PO_2 and that IHT simulates intense aerobic training it is possible that the periphery of these athletes' was

already well adapted to such hypoxic conditions. This possibility might explain the lack of improved performance following IHT.

For those who completed the study, compliance to the IHT protocol went well (Tables 3 and 4). However, the time taken to travel to and from the Hypoxicator venue, as well as the hour spent following the IHT protocol, posed a substantial time constraint on many subjects in the IHT group, particularly as almost all had full-time jobs and relatively heavy training schedules to complete. This time constraint was the main factor for the withdrawal of so many subjects in the IHT group prior to the second exposure. A 24-week training study is demanding on all involved and future researchers may want to consider reducing the length of the study to improve subject compliance.

Both groups demonstrated very high VO_2 max results, indicating high calibre athletes were recruited to the study. However, there was a significant difference between the IHT and control groups for VO_2 max results. Although VO_2 max has not always been shown to be a good predictor of endurance performance (Mahood et al., 2001), it is possible that the IHT group was of a higher calibre than the control group. This finding was probably due to chance because subjects were generally randomised to either group. The trend toward higher power at lactate threshold (Figures 14 and 15) would support this hypothesis.

If the IHT group contained higher-calibre athletes, the law of diminishing effects would suggest it would have been more difficult for this group to show improvements in the measures taken in this study. The law of diminishing

effects asserts that the closer an athlete is to their biological limit, the less effect can be gained from the same training compared to someone far from their biological limits.

Elite athletes have been shown to be more reliable than non-elite athletes in tests to simulate performance (Hopkins et al., 2001) and this improves the ability to detect a true treatment effect. This being the case, better reliability would have advantaged the IHT group in the 16-km time trial and probably also in the lactate threshold test. However, the within-subject coefficient of variation of the IHT group in the 16-km time trial was high. To improve the reliability in future studies, researchers should consider higher calibre subjects, reducing the time between tests, employing a constant power to exhaustion test or including a more reliable cycle ergometer set-up such as the SRM crank fitted to the cyclist's racing bike, which is placed on a Kingcycle ergometer (Hopkins et al., 2001).

For this study, the calibre of endurance athletes was close to the best that could have been recruited in the Christchurch area. SRM cranks were considered but their availability and the time required to fit and calibrate them on each cycle prevented their use. Reducing the time between the reliability tests would have helped detect the random error associated with the Kingcycle ergometer but more than two trials are required for this process. It would have been very difficult for subjects to maintain maximum-effort across several trials in a short period of time. Also, testing over four weeks was necessary to help characterize the typical training effect.

It is possible that one-hour sessions of IHT were not sufficient to create a biological adaptation. Rodriguez et al. (1999) found an improvement in performance by exposing subjects to high altitudes for three-five hours per day. In addition, the timing of the tests in this study may not have detected a possible effect of IHT. However, there appears to be no consensus in the literature, as significant improvements in performance have been detected three, five, sixteen and twenty-one days post-exposure (Faulkner et al., 1967; Burtcher et al., 1996; Mattila and Rusko, 1996). Haematological improvements have been observed one, fourteen and thirty days post-exposure (Ingjer and Myhre, 1992; Savourey et al., 1996; Bonning et al., 1997).

There are many variables surrounding the use of IHT that have not been characterized in the literature and were not examined in this study. The IHT protocol used was taken from the New Zealand distributor of the Hypoxicator and the protocol appears to comply with the small amount of scientific evidence available to help determine the best use of IHT (Mairbaur, 1994; Liu et al., 1998; Rodriguez et al., 1999). However, future studies need to clarify whether the athletes should be exercising or resting during IHT (Beidleman et al., 1997; Rodriguez et al., 1999) as well as the optimal frequency of exposure, duration of exposure, interval durations and percent of oxygen in the gas mixture.

The 16-km time trial lasted about 20min, so energy production would almost entirely be derived from the aerobic energy system. This study does not address the possibility that IHT may enhance performance in events lasting less than several minutes, which depend more on anaerobic capacity.

Summary

Advocates of IHT have proposed a positive effect on performance in the order of that found by Levine and Stray-Gundersen (1997). In our study, subjects demonstrated a gradual but erratic improvement in 16-km time trial performance and lactate threshold throughout the study, probably due to training. The IHT group did not appear to have gained a worthwhile additional improvement from either of the two exposures to IHT. Any effect cannot be ruled out as placebo since the effort-independent measures of haematocrit and haemoglobin do not support the increase in performance nor does the time exposed to IHT. There was a possible positive response in lactate threshold after exposure to IHT and subjects with the DD genotype for the ACE gene probably responded higher than others.

There are potential practical advantages of using IHT via the Hypoxicator. Firstly, the athlete avoids the drop in training quality experienced at moderate altitude training camps (Rusko, 1996) as a result of increased anaerobic glycolysis and the right shift in the oxygen dissociation curve (Mairbaur, 1994). Secondly, simulated altitude conditions are available without the athlete moving from their base, which allows familiarity in training conditions and equipment and a reduction in emotional stress (Liu et al., 1998). Thirdly, use of the Hypoxicator is substantially more cost-effective than attending a venue suitable for the live high - train low protocol.

The physiological benefits of IHT may arise from the body's increased ability to transport oxygen via the blood from the lungs to the mitochondria of the working muscle (central adaptations) or through the improved ability of the mitochondria to utilise the available oxygen in the Krebs Cycle (peripheral adaptations). It is clear that moderate and high altitude can impose central adaptations (Berlund, 1992; Mairbaur, 1994; Bonning et al., 1997) but, because of a limited number of studies, it is less clear whether very short bursts of high altitude will induce peripheral adaptations. The results of this study provide no evidence to support central adaptations.

No scientific studies directly address whether replicating the low muscular PO_2 observed at the end of short bursts of intense aerobic activity (Schibye et al., 1998) in a resting state imposes an adaptation beneficial for performance.

There is some research showing aspects of training and hypoxia produce similar physiological responses e.g. EPO release, red blood cell production, reduced mean cell age and change in the oxygen dissociation curve (Wolfel et al., 1991; Stray-Gundersen et al., 1993; Mairbaur, 1994; Rusko, 1996).

Unfortunately, this study did not address these proposed physiological mechanisms.

Future studies should continue to investigate performance enhancements by examining the percent of oxygen inhaled, protocol in which it is delivered and a longer duration of exposure (e.g. 3-5 hours). These studies should investigate effects on the anaerobic energy system as well as peripheral adaptations. More reliable ergometers (e.g. SRM cranks with tests performed on the Kingcycle), and tests of performance (e.g. constant power to exhaustion) should be

adopted or considerably more subjects should be recruited. Protein intake should be regulated and the length of the study should be reduced to improve compliance. Subjects should be randomised on the basis of performance or VO_2max and ACE genotype. It should also be noted that other simulated-altitude devices, which do not follow the IHT protocol, might be beneficial to performance.

Conclusion

The effect of the various devices that simulate moderate and high altitude on physiological parameters and endurance performance are currently not well understood despite a commercial focus in this area. Further, the research addressing the effect of IHT on performance is extremely limited and does not indicate a clear-cut, positive result. The data from this study show that IHT delivered through a nitrogen-mask device, called the Hypoxicator, using a protocol recommended by the distributor probably does not improve 16-km cycling time-trial performance in highly-competitive cyclists, multi-sport athletes and triathletes who underwent a similar training regime. Effort-independent measures of haematocrit and haemoglobin support this conclusion but lactate threshold may not.

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APPENDIX A

Information Sheet for Participants and Coaches in the IHT Group

ENHANCING PERFORMANCE OF NZ ATHLETES WITH INTERMITTENT SIMULATED ALTITUDE EXPOSURE

INFORMATION SHEET FOR PARTICIPANTS AND COACHES

Thank you for showing an interest in this project. Please read this information sheet carefully before deciding whether or not to participate. If you decide to participate we thank you. If you decide not to take part there will be no disadvantage to you of any kind and we thank you for considering our request.

The Aim of the Project

This project is being undertaken to provide information to interested national sports organisations and as part of the requirement for a Masters of Science.

The major aims of this project are as follows:

- a) enhance performance using simulated altitude exposure (nitrogen masks)
- b) measure the effect of intermittent altitude exposure via performance testing and blood samples
- c) determine effective methods of utilising the masks before a major competition
- d) track the effects of repeated altitude exposure
- e) compare the effectiveness between masks and altitude tents (from another similar study being carried out at the same time in Auckland)
- f) determine whether simulated altitude exposure raises your haematocrit (percent of red cells in your blood) to a limit that would bar you from competing.

Participant Criteria

The participants recruited for this project can be either male or female and should fulfil the following criteria:

- a) competitive cyclist
- b) cyclist participating in road events, or triathlons.

Exclusion Criteria

The following people will not be allowed to participate

- a) anyone suffering from illness or injury that would interfere with normal training and competition
- b) anyone intending to travel overseas during the period of the study
- c) anyone who has a haematocrit of 54% or more (males) or 47% or more (females) in the first blood test.

What will Participants Be Asked to Do?

As a participant you will be involved with this study for about 28 weeks. During this time you will acclimatise to high altitude and train at sea level for 12 weeks, consisting of 4 weeks of altitude exposure and 8 weeks of follow-up. No serious discomforts have been reported previously from the use of the masks. The benefit gained would be performance enhancement in competitive events.

Please turn over

Should you agree to take part in this project, you will be asked to do the following:

You will visit a clinic for daily 1-hour sessions breathing air containing down to 9% oxygen (equivalent to an altitude of 6000 m) generated by a *Hypoxicator*. This is a commercially available device and has already been used by several top-level athletes in Christchurch.

You breathe through a mask (delivering low oxygenated air) then breathe normal air alternately for repeated, short periods. The time you have the mask on and the period it will be taken off will be determined by your body's response to the low oxygenated air. This is monitored by a "pulse oximeter" which is a clip that is attached comfortably to one of your fingers and measures the percent saturation of oxygen in your blood. The oxygen percentage delivered from the mask will be reduced gradually during the course of the four weeks as you get used to the "simulated altitude". Eventually the percent saturation of the blood will be in the range 75-85%.

You may experience unusual discomfort when breathing the air in the mask. You must ask to see Dr Hellemans (or if he is not there, the doctor on duty at the clinic) if you are unduly disturbed by a headache or by feeling sick, dizzy or drowsy. The staff at the clinic are specialists in this field of study, they are familiar with the Hypoxicator, and Dr Hellemans has used the device himself.

All participants will also do the following:

- a) You will give a blood sample at the start of the study, then give blood samples before and after altitude exposure, at the end of the 4th week of non-exposure, and at the end of 8th week of non-exposure for two cycles (total of 8 samples).
- b) You will participate in 16km time trials in the sport science centre laboratory (University of Canterbury). There will be 1 familiarisation test, then 7 further tests at 4-weekly intervals.
- c) You will participate in laboratory performance tests to determine anaerobic threshold. The former test consists of a series of 5-min submaximal workloads of increasing intensity. At the end of each cycle a few droplets of blood are taken from a finger for measurement of blood lactate (lactic acid). There will be 1 familiarisation test, then 7 further tests at 4-weekly intervals. You will also undergo a VO₂max test to exhaustion before beginning the altitude exposure.
- d) You will complete a questionnaire to provide basic information about your age, weight, height, and competitive status.
- e) You will complete a daily diary of your training, response to training, and response to the altitude exposure each day throughout the whole study.
- f) You will take iron supplements if your initial blood test shows iron deficiency, and you will take iron supplements during the periods of altitude exposure, as prescribed by a sports nutritionist and sports doctor.
- g) You will provide a saliva sample that will be analysed for a particular enzyme. This test will be a one-off test to determine your individual response to altitude training.

Please turn over

Can Participants Change their Minds and Withdraw from the Project?

Your participation throughout the study will allow us to make the best assessment of the effects of altitude exposure on you personally and on the group as a whole. But, as for any research project of this nature, you are free to withdraw from the study at any time without having to give a reason and there will be no repercussions in doing so.

What Data or Information will be Collected? What Use will be Made of it?

The data collected are as follows:

- a) Blood samples to measure hematocrit and haemoglobin. These two parameters will demonstrate whether there is an increase in red blood cell mass with altitude exposure. Also to measure ferritin in your blood, to determine your iron status for prescription of iron supplements. This is to ensure your health status is not compromised.
- b) A saliva sample to determine your genotype for angiotensin converting enzyme. We think that people who have the one or two copies of the "I form" of this gene will have a better response to altitude exposure than those who have one or two copies of the "D form".
- c) Anaerobic threshold. This measure of performance is not affected by motivation. It is one of the best objective measures of endurance performance currently available.
- d) Time trials to monitor changes performance over distances similar to your specialty event. These data will help us determine when performance peaks after each period of altitude exposure (immediately, 4 weeks, or 8 weeks later).
- e) Hyperventilatory response and gene expression tests to determine whether the participants have the gene that predicts response to training and altitude.
- f) Training and altitude data in the daily diary.

Results of this project may be published but any data included will in no way be linked to any specific participant. The data collected will be securely stored in such a way that only those mentioned below will be able to gain access to it. At the end of the project any personal information will be destroyed immediately except that, as required by the University's research policy, any raw data on which the results of the project depend will be retained in secure storage for at least five years. You will be given a copy of the results of the project including your lactate profiles and time trial data, along with an assessment of your individual response to altitude exposure.

What if Participants have any Questions?

If you have any questions about this project at any stage please feel free to contact either:

Chris Bailey
Sport Science Centre
Recreation Services
Canterbury University
Work Number (03) 3642987 ext. 8416

Dr John Helleman
Sports Med QEII
Work Number: (03) 383 6290
Home Number: (03) 351 6684

Will Hopkins
Department of Physiology
University of Otago
Work Number: (03) 4797330

This project has been reviewed and approved by the Ethics Committee from the University of Otago

APPENDIX B

Information Sheet for Participants and Coaches in the Control Group

ENHANCING PERFORMANCE OF NZ ATHLETES WITH INTERMITTENT SIMULATED ALTITUDE EXPOSURE

INFORMATION SHEET FOR PARTICIPANTS AND COACHES IN THE CONTROL GROUP

Thank you for showing an interest in this project. Please read this information sheet carefully before deciding whether or not to participate. If you decide to participate we thank you. If you decide not to take part there will be no disadvantage to you of any kind and we thank you for considering our request.

The Aim of the Project

This project is being undertaken to provide information to interested national sports organisations and as part of the requirement for a Masters of Science.

The major aims of this project are as follows:

- a) enhance performance using simulated altitude exposure (nitrogen tents or masks)
- b) measure the effect of intermittent altitude exposure via performance testing and blood samples
- c) determine effective methods of utilising the tents or masks before a major competition
- d) track the effects of repeated altitude exposure
- e) compare the effectiveness between the tents and the masks
- f) determine whether simulated altitude exposure raises haematocrit (percent of red cells in your blood) to a limit that would bar athletes from competing.

Participant Criteria

The participants recruited for this project should fulfil the following criteria:

- a) competitive cyclist
- b) cyclist participating in road events, or triathlons.

Exclusion Criteria

The following people will not be allowed to participate

- a) anyone suffering from illness or injury that would interfere with normal training and competition
- b) anyone intending to travel overseas during the period of the study
- c) anyone who has a haematocrit of 54% or more (males) or 47% or more (females) in the first blood test.

What will Participants in the Control Group be Asked to Do?

As a participant you will be involved with this study for about 28 weeks. Most of the action occurs in the first 24 weeks, when the experimental group is being exposed to simulated altitude. Your role as a member of the control group is to train and be tested in the same manner as the experimental group.

Please turn over

You will be asked to do the following:

- a) You will give a blood sample every four weeks (a total of 9 samples). During each visit to the lab your skinfold thickness will be measured, to track any changes in body fat throughout the study.
- b) You will take iron supplements if your initial blood test shows iron deficiency, as prescribed by a sports nutritionist and sports doctor.
- c) You will perform a standard incremental test to maximum effort in the laboratory, for measurement of maximum oxygen consumption.
- d) You will participate in laboratory tests to determine anaerobic threshold. The test consists of a series of 5-min submaximal stages of exercise at increasing intensity. At the end of each stage a few droplets of blood are taken from a finger or earlobe for measurement of blood lactate (lactic acid). There will be eight tests altogether, at 4-weekly intervals.
- e) You will complete a questionnaire to provide basic information about your age, weight, height, and competitive status.
- f) You will complete a daily diary of your training and response to training.

Can Participants Change their Minds and Withdraw from the Project?

Your participation throughout the study will allow us to make the best assessment of the effects of altitude exposure. But, as for any research project of this nature, you are free to withdraw from the study at any time without having to give a reason.

What Data or Information will be Collected? What Use will be Made of it?

The data collected are as follows:

- a) Blood samples to measure hematocrit and haemoglobin. These two parameters will demonstrate whether there is an increase in red blood cell mass with altitude exposure. Also to measure ferritin in your blood, to determine your iron status for prescription of iron supplements. This is to ensure your health status is not compromised.
- b) Maximum oxygen consumption. This is a standard measure to describe the calibre of endurance athletes in a research study.
- c) Anaerobic threshold. This measure of performance is not affected by motivation. It is one of the best objective measures of endurance performance currently available.
- d) Training data in the daily diary.

Results of this project may be published but any data included will in no way be linked to any specific participant. The data collected will be securely stored in such a way that only those mentioned above will be able to gain access to it. At the end of the project any personal information will be destroyed immediately except that, as required by the University's research policy, any raw data on which the results of the project depend will be retained in secure storage for at least five years.

You will be given a copy of the results of the project.

Please turn over

What if Participants have any Questions?

If you have any questions about our project, either now or in the future, please feel free to contact either:

Chris Bailey
Sport Science Centre
Recreation Services
Canterbury University
Work Number (03) 3642987 ext. 8416

Will Hopkins
Department of Physiology
University of Otago
Work Number: (03) 4797330

Dr John Helleman
Sports Med QEII
Work Number: (03) 383 6290
Home Number: (03) 351 6684

This project has been reviewed and approved by the Ethics Committee
of the University of Otago

APPENDIX C

Brief Summary of IHT Group Participants' Initial Requirements

ENHANCING PERFORMANCE OF NZ ATHLETES WITH INTERMITTENT SIMULATED ALTITUDE EXPOSURE

BRIEF SUMMARY OF YOUR INITIAL REQUIREMENTS

- Read Subject Information Sheet
- Ask Any Questions
- Sign Informed Consent Form
- Questionnaire Regarding Competition Data
- Training Information Sheet

31 June – 19 July.

TEST 1 - 1 hour

Height

Weight

VO₂max (Cycling NZ Protocol) and examine the oxygen saturation in the blood.

Two blood lactate samples will be taken.

Blood Testing at Southern Communities Laboratories (in the morning before your first training session of the day) - 15 mins

Analysed for Iron, Haemoglobin, Haematocrit (amount of red blood cells).

TEST 2 (at least 72hrs after Test 1) – 45 mins

16km Time Trial and examine the oxygen saturation in the blood.

Train for 4 weeks with the 4th week being easy (before testing).

29 July – 3 August.

TEST 1 – 1 hour

Weight

16km Time Trial and examine the oxygen saturation in the blood.

Blood Testing at Southern Communities Laboratories (in the morning before your first training session of the day) - 15 mins

TEST 2 (at least 72hrs after Test 1) - 45 mins

Anaerobic Threshold Test (not a maximal-effort test).

APPENDIX D

Brief Summary of Control Group Participants'

Initial Requirements

ENHANCING PERFORMANCE OF NZ ATHLETES WITH INTERMITTENT SIMULATED ALTITUDE EXPOSURE

BRIEF SUMMARY OF YOUR INITIAL REQUIREMENTS

- Read Subject Information Sheet
- Ask Any Questions
- Sign Informed Consent Form
- Questionnaire Regarding Competition Data
- Training Information Sheet

31 June – 19 July.

TEST 1 - 1 hour

Height

Weight

VO₂max (Cycling NZ Protocol) and examine the oxygen saturation in the blood.
Two blood lactate samples will be taken.

Blood Testing at Southern Communities Laboratories (in the morning before
your first training session of the day) - 15 mins
Analysed for Iron, Haemoglobin, Haematocrit (amount of red blood cells).

Train for 4 weeks with the 4th week being easy (before testing).

1 August – 10 August.

TEST 1 – 1 hour

Weight

Anaerobic Threshold Test (not a maximal-effort test).

Blood Testing at Southern Communities Laboratories (in the morning before
your first training session of the day) - 15 mins

APPENDIX E

Participant Consent Form

ENHANCING PERFORMANCE OF NZ ATHLETES WITH INTERMITTENT SIMULATED ALTITUDE EXPOSURE

CONSENT FORM FOR PARTICIPANTS AND COACHES

I have read the Information Sheet concerning this project and understand what it is about. All my questions have been answered to my satisfaction. I understand that I am free to request further information at any stage.

I know that:-

1. my participation in the project is entirely voluntary;
2. I am free to withdraw from the project at any time if absolutely necessary without any disadvantage;
3. the data will be destroyed at the conclusion of the project but any raw data on which the results of the project depend will be retained in secure storage for five years, after which it will be destroyed;
4. the only discomfort involved in this project is the prickling of the needle or small lancet during blood sampling, and the maximum effort in time trials;
5. the results of the project may be published but my anonymity will be preserved.

I agree to take part in this project.

.....

(Signature of participant)

.....

(Date)

.....

(Print name of participant)

This project has been reviewed and approved by the Ethics Committee
of the University of Otago

APPENDIX F

Letter to Coaches Regarding the Periodisation of Training

ENHANCING THE PERFORMANCE OF NZ ATHLETES WITH INTERMITTENT SIMULATED ALTITUDE EXPOSURE

PERIODISATION OF TRAINING

To the coach,

Training at altitude is becoming increasingly popular for endurance athletes in an attempt to enhance performance. Around 3% improvement can be expected. ***This can be the difference between winning and losing at the elite level!*** Consequently, NZ sports have targeted altitude training as an area of high importance as they prepare for the Sydney 2000 Olympics.

A device, called the ***Hypoxicator***, has arrived recently in Christchurch. It's an exciting new way of exposing athletes to altitude because it's easy to use, is relatively inexpensive, and doesn't cause the fatigue experienced at high altitudes (thereby maintaining training quality). It involves breathing through a mask that fits comfortably over the nose and mouth, which is attached to a unit delivering low-oxygenated air. Participants control the percentage of oxygen delivered through the mask. Elite athletes in Christchurch are currently using the Hypoxicator with success.

A research project, funded by Sport Science NZ, has been set up to test the benefits of using the Hypoxicator. I currently work as a sports trainer and I'm running this project as part of my Masters of Science degree.

Because the benefits of altitude training are small (3%), it is absolutely imperative that everyone is thorough about testing and training. Testing occurs every 4 weeks, and *we would like you to make sure that your cyclist is in a fresh condition leading up to the tests*. This will make sure that your cyclist gets **true** results. It will also ensure that the true improvements from the altitude training are discovered, and not undetected because your cyclist was fatigued! ***We would ask that you schedule 4-week macrocycles, with the final week being an easier, unloading week – the week before testing.***

If you have any questions or would like to discuss your training schedule further, please do not hesitate to contact me on 3642987 ext. 8416.

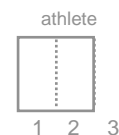
Thank you for your kind co-operation,

Chris Bailey
Sport Science Centre, University of Canterbury

APPENDIX G

Training Diary for Participants

TRAINING and ALTITUDE DIARY: Cyclists & Triathletes



- Use one box per digit. Please CHECK you have used the right number on the right scale.
- Record training and daytime altitude data soon after the sessions. Measure saturation at end of session.
- In the evening record alcohol and extent of feeling stressed out or anxious during the day.
- Next morning record overnight quality of sleep.
- Record weight after voiding before breakfast.

TRAINING SESSIONS												ALTITUDE EXPOSURE					COMMENTS																
1 = weights 2 = run continuous 3 = run intervals 4 = cycle continuous 5 = cycle intervals 6 = swim continuous 7 = swim intervals 8 = other				symptoms during the session 1 = easy 2 = steady 3 = mod-hard 4 = hard 5 = very hard 1 = none 2 = low 3 = medium 4 = high 5 = severe 1 = very good 2 = good 3 = average 4 = bad 5 = very bad				symptoms on hypoxicator 1 = none 2 = low 3 = medium 4 = high 5 = severe																									
session no. today		day month		type of session		duration of session (min)		Intensity		fatigue		session rating		Session #1 time on hypoxicator hours mins saturation (%)					Session #2 time on hypoxicator hours mins saturation (%)					EVENING alcohol today cansglasses stressed out					1 = none 2 = low 3 = medium 4 = high 5 = severe				
#1		1 2 3 4		5 6 7 8		9 10 11 12		13 14 15 16		17 18 19 20		21 22 23 24		25 26 27 28		29 30 31 32 33 34					35 36 37 38 39					40 41 42							
#2		1 2 3 4		5 6 7 8		9 10 11 12		13 14 15 16		17 18 19 20		21 22 23 24		25 26 27 28		43 44 45 46 47 48					49 50 51 52 53					54 55 56 57							
#3		1 2 3 4		5 6 7 8		9 10 11 12		13 14 15 16		17 18 19 20		21 22 23 24		25 26 27 28		43 44 45 46 47 48					49 50 51 52 53					54 55 56 57							
												Session #2 time on hypoxicator hours mins saturation (%)					oxygen gas (%) head-ache breathing nausea hard					NEXT MORNING weight (kg) sleep					1 = very good 2 = good 3 = average 4 = bad 5 = very bad						